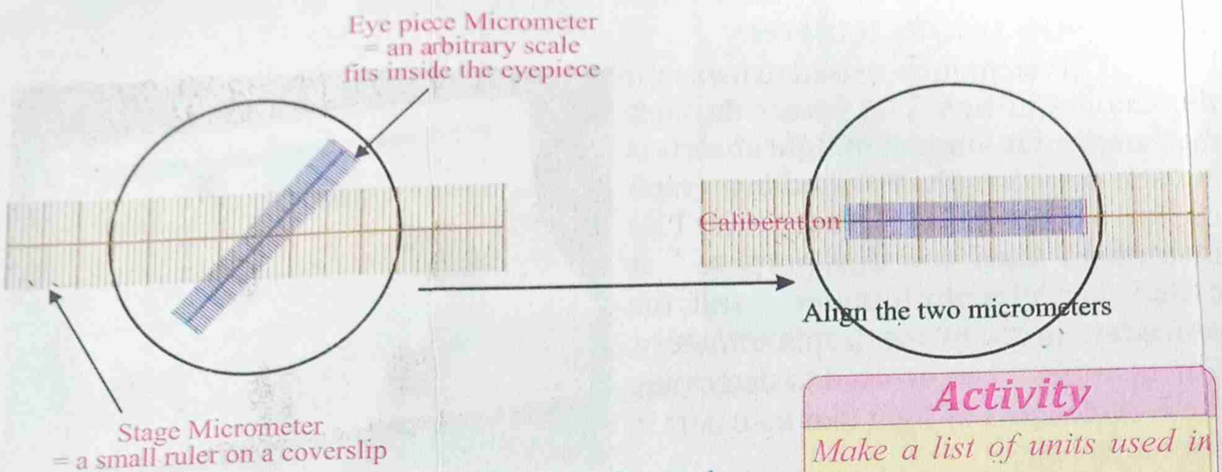


Fig. 1.6 Graticule

Activity

Make a list of units used in micrometery.

The stage micrometer is a glass slide on which a series of vertical lines are present (100 divisions). Its total length is 1mm.

1mm = 100 divisions

100 divisions = 1000 micrometers

1 division = 0.01mm (10μm)

Do you know?

A micron is an abbreviated term for micrometer. This is about 0.00004 inches or 1/1,000,000 meter.

1.2 Cell wall and plasma membrane

Structure of Cell

The cell consists of following parts.

1.2.1 Cell wall

Cell wall is the outer most nonliving covering present in Plants, Algae, Fungi and Prokaryotes. It is secreted by the protoplasm of the cell. Its thickness and composition varies in different groups of organisms. Here we will discuss the detail of plants cell wall.

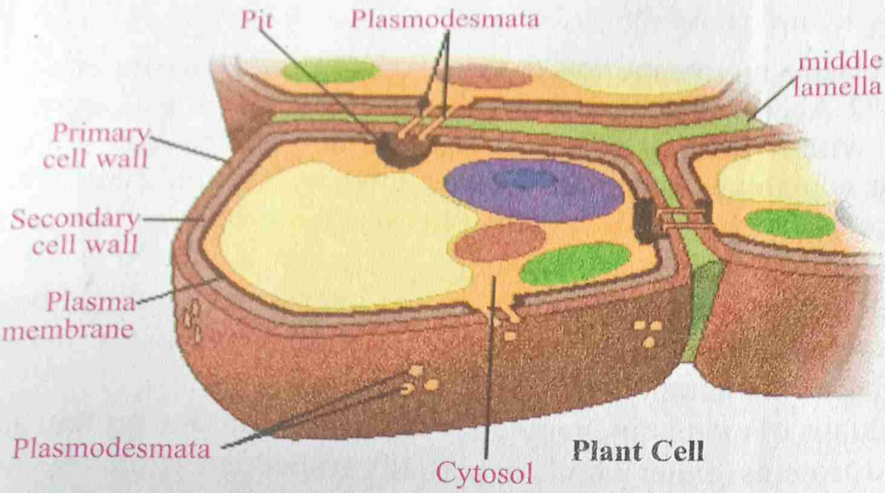
Tit bits

The plasma membrane is outer living membrane of all the cells. Many cells have rigid or semi rigid dead covering outside the cell membrane called cell wall.

Structure and composition of cell wall

The plant cell wall consists of three layers i.e primary cell wall, middle lamella and secondary cell wall.

Primary cell wall is a true wall formed in developing cells. Some plant cells possess only primary cell wall such as leaves, storage cells and young growing cells. Primary cell wall is composed of **cellulose, hemicellulose** and **pectin**. The outer part of primary cell wall of plant epidermis is usually impregnated with cutin and wax, forming a permeability barrier known as plant cuticle. The cellulose microfibrils are arranged in criss cross manner. The microfibrils are held together by hydrogen bond to provide high **tensile strength.**



Plant Cell

Cellulose Fibrils

Fig. 1.7 Plant Cell Walls

Middle lamella

It is the first layer that is deposited at the time of cell division between two adjacent cells. It is formed of sticky gel like magnesium and calcium salts of proteins which help to stick the neighbouring cells together.

Secondary cell wall is thick layer formed between the primary cell wall and plasma membrane. The secondary cell wall is formed when the cell is fully grown. It is composed of cellulose, hemicellulose and lignin which is used to strengthen the wall. In the secondary cell wall the microfibrils also show criss cross arrangement. Cells with secondary cell walls are rigid.

1.2.2 Plasma Membrane

It is outer most living boundary of animal cells while in plant cell, it is always present after the cell wall. There are many other membranes bounded organelles, like mitochondria, Golgi bodies, Endoplasmic reticulum. All these membranes are chemically composed of 60- 80% proteins, 20 to 40% lipids and small amount of carbohydrates.

Tit bits

Cellulose, the main constituent of cell wall, is used in the manufacturing of paper, cotton goods, sellotape, ropes etc.

Do you know?

Cell wall provides mechanical strength shape, support and protection to cell.

Do you know?

Plant cells are communicated with each other by microscopic channels known as

Tit bits

The plasma membrane consists of 3 classes of amphipathic lipids, phospholipids, glycolipids and sterols. The amount of each depend on the type of cell. Usually phospholipid is most abundant.

Fluid mosaic model:

This model of plasma membrane was developed by **Jonathan Singer** and **Garth Nicolson** in 1972. According to this model plasma membrane is fluid mosaic of protein, floating within bilayer of phospholipid and cholesterol. The phospholipid molecule contains a hydrophilic head and two hydrophobic tails. The hydrophobic tails face each other while hydrophilic heads are directed towards water which is present outside and inside the cell.

The cholesterol molecules are embedded in the interior of the membrane which makes the membrane less permeable for water soluble substances. It also provides stability to plasma membrane.

There are two kinds of membrane proteins, **extrinsic** or surface protein and **intrinsic** or embedded proteins (either wholly or partially embedded in bilayer).

Some amount of carbohydrates are also present in plasma membrane. These may either attach with protein as glycoproteins or attached with lipids as glycolipids.

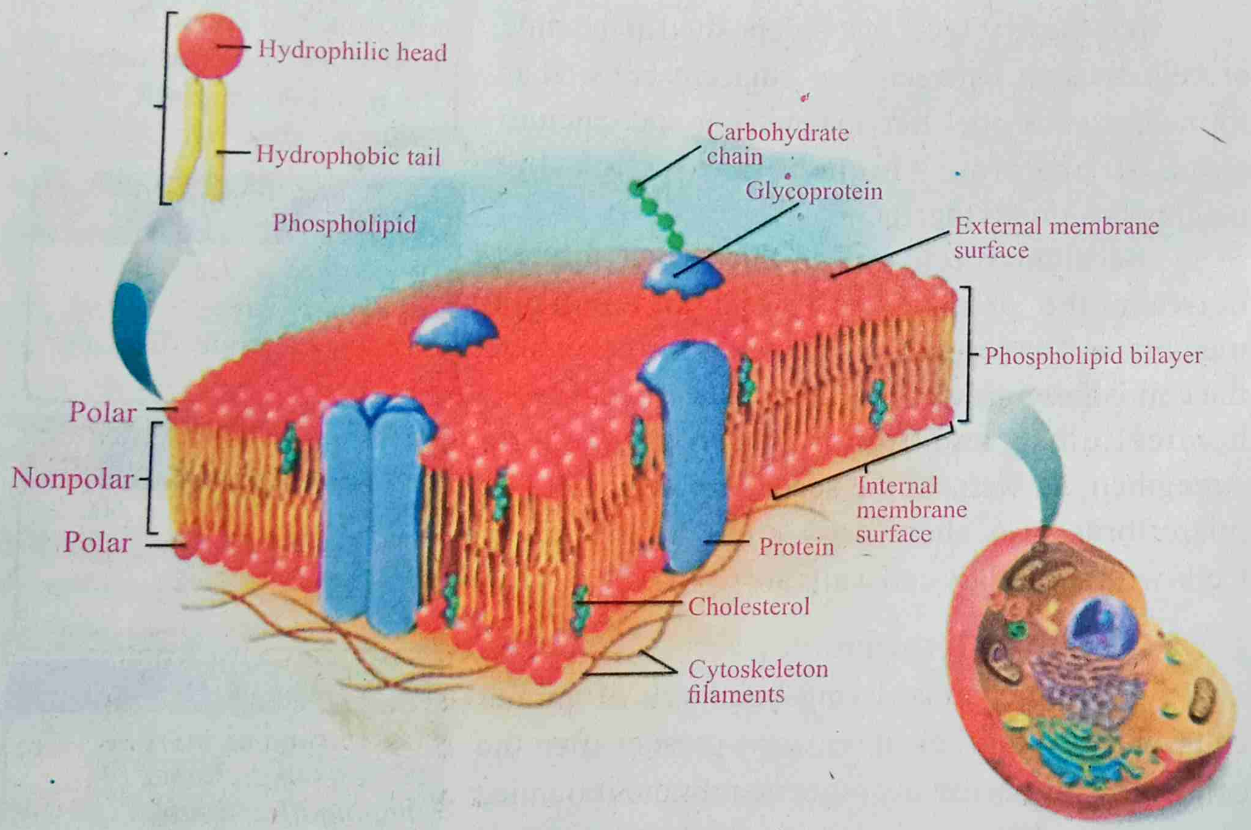


Fig. 1.8 Fluid Mosaic Model of Plasma Membrane

The role of glycoproteins and glycolipids:

They provide receptor sites for hormones, nerve impulses, recognition of antigens and also responsible for endocytosis. Therefore, these are called as cell

surface markers. Cell to cell recognition, sticking, correct cell together. They are just like signboard on a shop.

Protein of plasma membranes:

Channel proteins and carrier proteins:

These are involved in the passage of molecules through the membranes. Some proteins have channels through which substances can move across the membrane while other molecules combine with carrier proteins to move across the membrane.

Enzymes:

Some proteins of plasma membrane act like enzymes, e.g., the epithelial cells lining, some parts of the digestive tract contains digestive enzymes on their cell surface membrane.

Receptor molecules:

Some proteins of plasma membrane act as receptors e.g., hormones are chemical messengers, circulating in the blood but only bind to specific target cells which have the correct receptor site.

Antigens:

Antigens are glycoproteins have different shapes, so each cell can have its own specific marker. e.g., foreign antigens can be recognized to defend the cell.

1.2.3 Role of plasma membrane with its environment

It regulates materials moving into and out of the cell. It secretes useful substances such as enzymes, hormones etc. It removes waste and toxic substances such as ammonia, urea, uric acid. It keeps a constant favorable ionic concentration within the cell for enzymatic activities and for nervous and muscular activities. The transport of substances across the plasma membrane takes place by endocytosis, exocytosis, osmosis, diffusion etc.

1.3 Cytoplasm and Organelles

The living contents of the eukaryotic cells are divided into nucleus and cytoplasm, these two together known as protoplasm. The word "cytoplasm" literally means "living gel of cell". It is liquid substance lying inside cell membrane and outside nucleus. The cytoplasm is a mixture of organic and inorganic materials and form a solution having all fundamental molecules of life i.e., amino acids, sugars, fatty acids, nucleotides, vitamins, salts and dissolved gases.

The soluble part of the cytoplasm is called **cytosol** which is about 90% water, the small molecules and ions form true solution and large molecules form **colloidal**

solution (Such as starch particles in plant cells and glycogen granules of animal cells). The colloidal solution may be in the form of a sol (non viscous) or gel (viscous) parts.

Fig. 1.9 Colloidal Solution

Cytoplasmic Organelles:

These are highly organized cellular bodies which perform specific functions. Such as endoplasmic reticulum, ribosome, Golgi bodies Mictochondria, plastid, centrioles, lysosomes etc.

Functions: Store House:

The cytoplasm serves as store house of vital materials, chemicals e.g., glycogen in liver cells.

> **Tit bits**
>
> *Colloidal solution is a type of solution which contain tiny particles of a substance suspended in it.*

Site for metabolic activities:

It is the site of certain metabolic pathways e.g., glycolysis.

Maintain the cell shape:

The cytoskeleton present in the cytoplasm, not only maintains the shape of the cell but also helps in the movement of organelles.

1.3.1 Endoplasmic Reticulum (E R)

Endoplasmic reticulum is a network of channels or tubules in contact and extending between nuclear membrane and cell membrane of all eukaryotic cells. The components of endoplasmic reticulum are:

Cisternae: These are long flattened and unbranched units arranged in stack

Vesicles: These are oval membrane bounded structures.

Tubules: These are irregular often branched tubes bounded by membrane. Tubules may be free or connected with cisternae.

Endoplasmic reticulum divides the intracellular space into two distinct compartments, i.e., luminal (inside) and extra luminal (cytoplasm).

Types: There are two types of endoplasmic reticulum, Rough ER and Smooth ER.

Modification of Endoplasmic Reticulum:

In skeletal and cardiac muscle cells SER is known as sarcoplasmic reticulum (SR). These store calcium ions in their lumen. If many ribosomes are attached on the small parallel cisternae of RER, then it is called **ergastoplasm.** In nerve cells the **ergastoplasm** is known as **Nissl's body.**

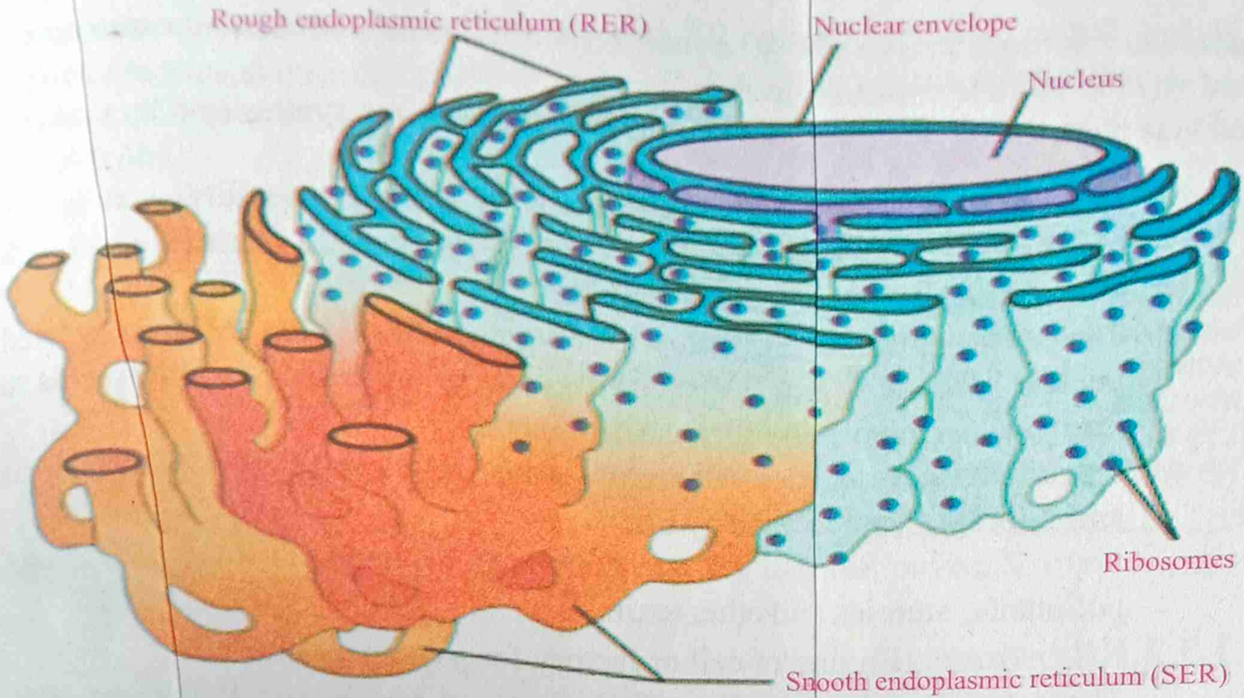


Fig. 1.10 Rugh Endoplasmic Reticulum (RER) and Smooth Endoplasmic Reticulum(SER)

Table 1.1 Differences between smooth andrough ER

Rough ER	Smooth ER
• *Ribosomes are attached with their outer surface.*	• *Ribosomes are not attached with their outer surface.*
• *More stable structure*	• *Less stable structure.*
• *Mainly composed of cisternae and vesicles*	• *Mainly composed of tubules*
• *Abundantly occur in cells which are actively engaged in protein synthesis and secretion, such as in liver, pancreas and goblet cells.*	• *Abundanly occur in the cells concerned with glycogen and lipid metabolism, such as in adipose tissues, muscles, liver cells, and also remove toxins*

Functions of ER:

i) Mechanical Support: Along with microfilaments and microtubules, ER gives mechanical support to the cell.

ii) Intracellular Exchange: The ER forms intracelular connecting system and transports material of the cell from one part to another part of the cell.

iii) Connection: The ER also helps in connecting nuclear material with plasma membrane.

iv) Protein synthesis: Rough ER helps in protein synthesis as ribosomes are attached with their outer surface.

v) Lipid Synthesis: Cholesterol and phospholipid are synthesized by smooth ER.

vi) Cellular Metabolism: The membranes of ER increase surface area for metabolic activities also contains some enzymes like, sucrases, glucose 6 phosphatase, NAD diphosphatase etc.

vii) Formation of Nuclear membrane: Fragmented elements of disintegrated nuclear membrane and E.R elements arrange around the chromosomes to form nuclear membrane during cell division.

viii) Formation of Organelles: All membranous organelles except mitochondria and chloroplast are formed by ER.

ix) Detoxification: Smooth ER are concerned with detoxification of drugs, pollutants, steroids and other toxins.

1.3.2 Ribosomes (Engine of cell or factory for protein synthesis)

These are granular structures first observed by George Palade in 1953. Ribosomes are **non membranous organelle**, present both in prokaryotic as well as eukaryotic cells (except mammalian RBCs). It is one of smallest cell organelle and also called organelle with in an organelle.

Composition: They are also known as ribonucleoprotein particle of the cell because composed of proteins and rRNAs. In prokaryotic ribosomes the amount of rRNA is 60% while protein is 40%. In eukaryotic ribosomes, protein is 60% and rRNA is 40%.

Location: The ribosomes exist in two forms, either freely scattered in cytoplasm or attached to outer surface of RER and nuclear membrane. It is also present in mitochondria and chloroplast.

Number: Numerous in number, about half a million ribosomes in a common eukaryotic cell.

Site of Synthesis: The subunits of ribosomes are synthesized in nucleolus of nucleus then transported to cytoplasm via nuclear pores. Thus nucleolus is the factory of ribosomes while ribosomes are the factory of proteins.

Subunits of Ribosomes A complete eukaryotic ribosome consists of two subunits, based on their sedimentation (S) rate. "S" stands for Svedberg unit. A larger sub unit of 60s and smaller sub unit of 40s. Both units collectively make 80s particle. These

Do you know?

Svedberg unit is a unit of time equal to 10^{-13} seconds used in expressing sedimentation coefficients

subunits are attached with each other by means of Mg ions or forming salt bonds between phosphate group of rRNA and amino group of amino acids or both by Mg ions and salt bonds. In prokaryote ribosome is 70s, larger unit is 50s while smaller unit is 30s.

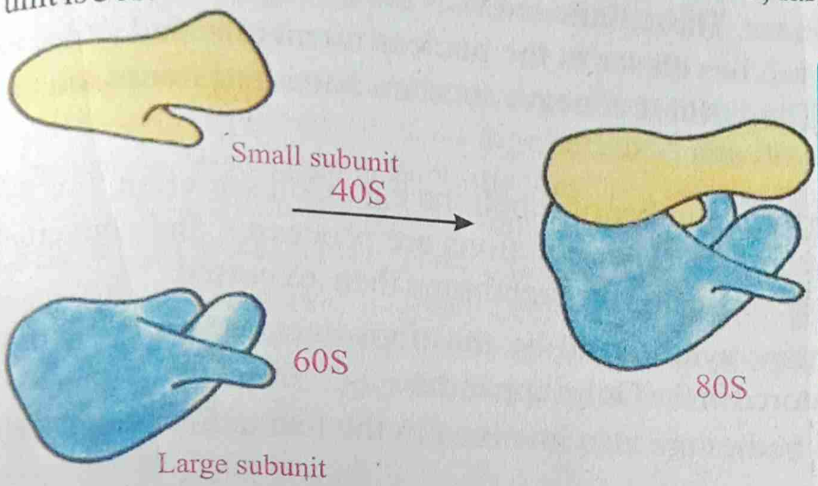


Fig. 1.11 Ribosome

> **Tit bits**
>
> *Mitochondrial ribosomes of eukaryotic cell are produced from mitochorndrial genes and functionally resemble many features of bacteria reflecting the likely evolutionary origin of mitochondria.*

Polysome

When many ribosmes attached to one mRNA strip, it is called polysome or polyribosomes. This happens during protein synthesis.

Function: Ribosomes are involved in protein synthesis which is facilitated with the help of three types of RNA and under the instructions of DNA.

> **Tit bits**
>
> *Golgi apparatus is a major collection and dispatch station of protein products, received from endoplasmic reticulum and known as post office of cell.*

1.3.3 Golgi Complex

They were discovered by Camillo Golgi in 1898, so called as Golgi complex or Golgi apparatus. In plants they are known as dictyosome.

Structure: The term Golgi apparatus refers to a set of smooth membranes that are stack into flattened, fluid filled sacs or cisternae, containing proteins, carbohydrates, glycoproteins and specific enzymes.

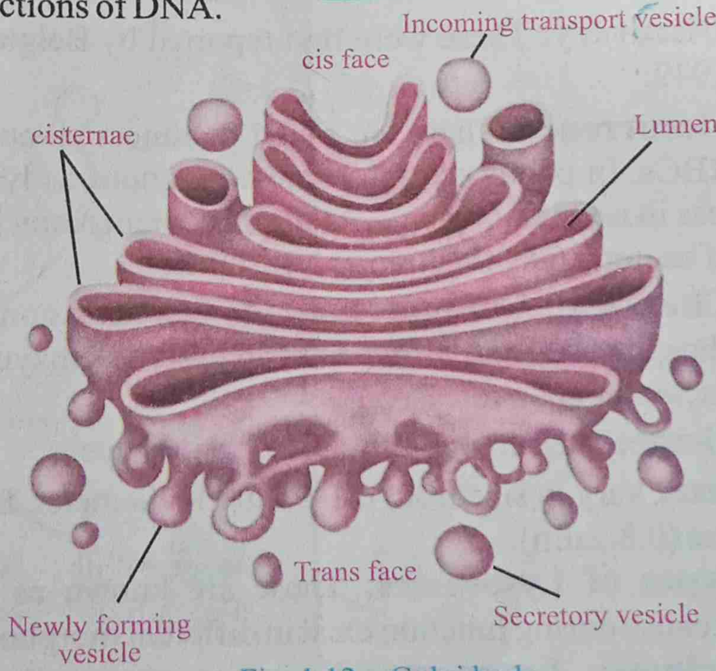


Fig. 1.12 Golgi body

Most of the Golgi apparatus is formed of flattened sacs or cisternae but some tubules and vesicles may also participate in the formation of Golgi complex. The number of cisternae ranges between 3-7 in most of animals but in lower organisms may have up to 30 flattened sacs. These flattened sacs are arranged in a concentric fashion, the convex face or sac lies closer to the nuclear membrane and called as Cis-Golgi or forming face. The farthest concave sacs are named as trans Golgi or maturing face.

Function: Golgi bodies perform number of functions e.g., Cell secretion: It is the main function of the Golgi complex. The secretions are processed and converted into finish products and are packed inside the membrane then exported.

Storage of proteins: Proteins synthesized by the ribosomes are passed to the endoplasmic reticulum and stored in the Golgi apparatus.

Cell wall formation: Golgi bodies are also involved in the formation of new cell wall by the plants.

Formation of Lysosomes: An important function of Golgi apparatus is the formation of primary lysosomes.

Formation of acrosome during spermiogenesis

Formation of vitelline membrane of egg is also secreted by Golgi bodies.

1.3.4_Lysosomes

Lysosomes (Gk. lyso: splitting, soma: body) are sac-like single membrane bounded organelles which break macromolecule in the cells.

Discovery: These were first reported by Belgian biologist Christian De Duve in 1949.

Occurrence: These are found in almost all eukaryotic cells except mammalian RBCs. In plants central vacuole functions as lysosome, therefore, lysosomes are less in number in plants. All fungi contain many lysosomes. The periplasmic space of bacteria may function as lysosome.

Chemical Composition: Lysosomes contain many enzymes like acid phosphatases and all types of hydrolytic emzymes, like carbohydrases, lipases, nucleases and proteases.

Shape: They are roughly spherical in shape.

Size: Vary in size from 0.1-0.8μm in diameter. In phagocytic WBC it is largest in size (0.8-2μm).

Types of Lysosomes: These are known as polymorphic cellular organelles because during function exist in different morphological and physiological states.

Primary Lysosome: Enzymes are synthesized by ribosomes of rough

endoplasmic reticulum and then taken to Golgi bodies where these are processed and budded off as Golgi vesicles, called primary lysosomes.

Secondary Lysosome: They are also called digestive vacuoles. They are formed by the fusion of primary lysosome with food vacuole known as phagosome (phagocytic food vacuole).

Residual Bodies or Tertiary Lysosome: Lysosome containing undigested materials after the absorption of digested food into the cytoplasm is called residual lysosome. In unicellular organisms these are removed outside of cell by exocytosis while in multicellular organisms these are retained in the cell as lipofuscin granules.

Autophagic lysosomes: Also called autophagosomes or cytolysosomes. When primary lysosome fused with dead cellular organelles such as mitochondrion which die after ten days to be digested are called autophagosomes, such as human liver cells recycle half of its macro molecules each week.

Functions of Lysosomes: Lysosomes perform many functions inside and outside of cells. Which are as under:

Intracellular digestion: Foreign substances received by the cells either by phagocytosis (solid molecules) or pinocytosis (liquid molecules) are digested by lysosome. This process is called heterophagy. The old or dead cell organelles are digested by lysosomes and stored food is also digested during starvation. This process is known as autophagy.

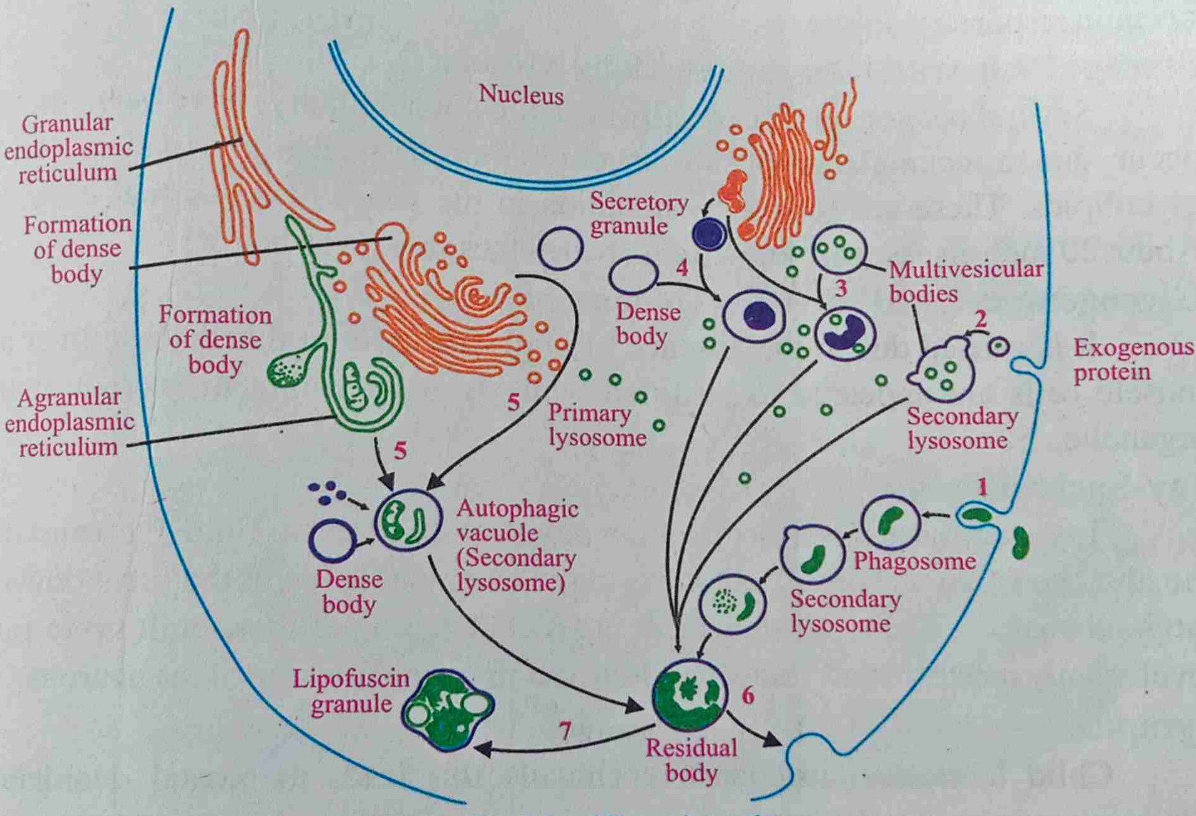


Fig. 1.13 Explained Function of Lysosome

Extra cellular digestion:

Lysosomes also help in extra cellular digestion by releasing enzymes. e.g., the lysosomes of osteoclast (Bone eating cells) dissolve unwanted parts of bone. Extracellular digestion also take place in fungi.

Autolysis:

Some time all lysosomes of cell burst to dissolve the cell completely. Thus also called suicidal bags because old cells like WBCs, platelets and epithelial cells are removed by autolysis. It also destroys unwanted organs of embryo such as tail of human embryo and tail of tadpole.

Crinophagy:

The excess hormones of endocrine gland may be digested by lysosome. This process is known as crinophagy.

Exocytosis or cell excretion:

Sometimes enzymes of primary lysosomes are released from the cell. This occurs during replacement of cartilage by bone during development. Similarly the matrix of bone may be broken down during remodeling of bone that can occur in response to injury.

> **Tit bits**
>
> *Glycogen-storage disease (GSD) may be treated by taking small meals of carbohydrate, in USA one child per 25000, births have GSD.*

Storage Diseases (Diseases due to faulty lysosomes)

Several congenital diseases (by birth but not hereditary) have been found to occur due to accumulation of substances within cell. Such as glycogen or various glycolipids. These are caused by mutation in the genes of lysosomal enzymes. About 20 such diseases are known e.g., two of these are given below:

Glycogenesis type II disease (G-Storage disease)

It is caused due to the absence of D-glycosidase. In this disease liver and muscle cells are appeared to be filled with glycogen within membrane bound organelle.

Tay-Sachs disease:

Tay-sach disease is a rare disorder passed from parent to child. It is caused by the absence of an enzyme (Beta hexosaminidase) that helps in the breakdown of fatty substances. These substances in brain called gangliosides, built up to toxic level mainly in babies and young children and affect the function of the neurons.

Symptoms

Child loses muscle control eventually this leads to mental retardation, blindness, paralysis and even death.

1.3.5 Mitochondria (Gk. mitos : thread, chondrion: granules)

Mitochondria (Singular mitochondrion, **Power house of the cell**) look like small thread or granule either spherical or elongated. It is self replicating organelle.

Altman (1890) established them as cell organelle and called them bioblast. The term mitochondria was given by C. Benda (1898).

Size:- The diameter of mitochondria is 0.2-1 μm while length is one μm to 4.1 μm. Their numbers are few to many thousand per cell, depending upon physiological activity of the cell.

Chondriome:- All the mitochondria present in a cell are collectively called chondriome. Usually animal cell have more mitochondria than plants.

Structure:- It is double membrane structure. The outer membrane is smooth while the inner membrane is folded. If outer membrane of mitochondria is removed then it is called as **mitoplast.** The folds of inner membrane are known as **cristae** which increase surface area for chemical reactions. These cristae contain (bear) pin head particles called **oxysomes** or elementary particles or F1 particles. Inside the inner membrane a fluid is present called matrix. The matrix contains enzymes for cellular aerobic respiration, proteins, 70s ribosomes, RNA and double stranded circular DNA. (It is 1% of total DNA of cell.) This DNA can code the synthesis of some type of proteins.

Tit bits

mitochondria is also called

- *Power house of the cell or ATP mill in cell.*
- *Cell within cell.*
- *Cell furnace or storage batteries.*
- *Most busy and active organelle in cell.*
- *Semi autonomous cell organelle.*

Tit bits

F1 particles or oxysomes are knob like structures located on cristae of mitochondria and they are helpful in cellular respiration. They contain ATP synthetase which is responsible for the synthesis of ATP.

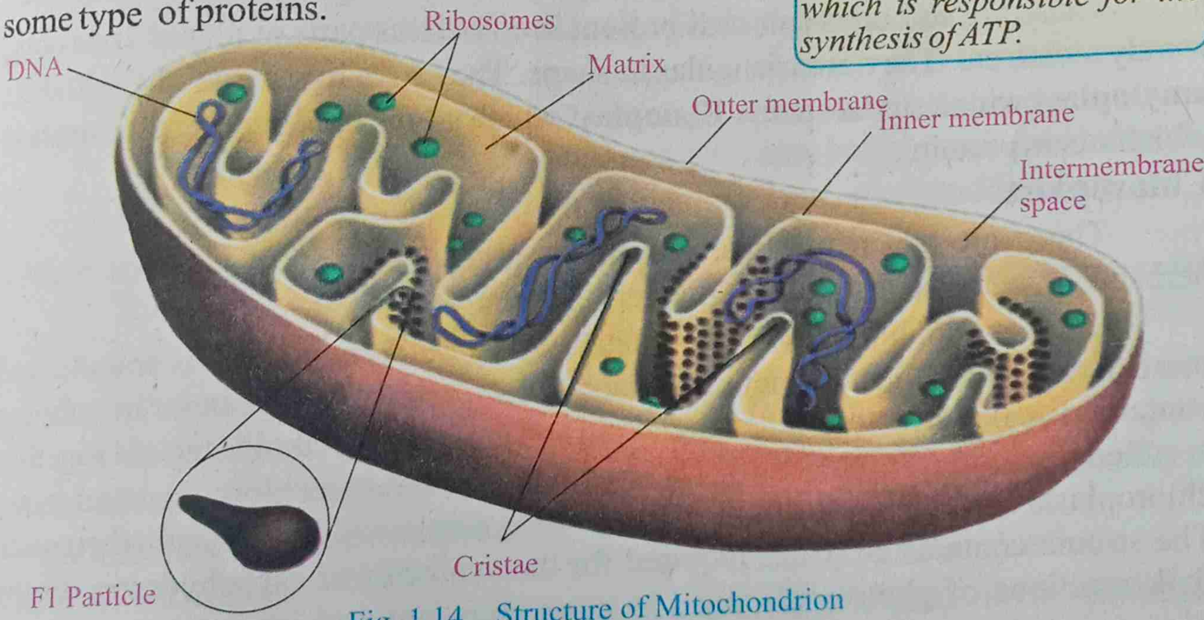


Fig. 1.14 Structure of Mitochondrion

Function of Mitochondria:

They provide site of aerobic respiration. Most of the oxidative metabolism and ATP production occurs in mitochondria. Therefore mitochondria are called power houses of the cell.

$$C_6H_{12}O_6 + 6O_2 + Pi + ADP \longrightarrow 6CO_2 + 6H_2O + ATP$$

Mitochondria also help in vitellogenesis (Yolk formation) in oocyte.

> **Tit bits**
>
> *It is believed that mitochondria have endosymbiotic origin from purple sulphur bacteria or prokaryotic cell. The ribosome of mitochondria and DNA are similar to prokaryotic cell.*

1.3.6 Plastids

The plastid (Gk. Plastos: formed, molded) is a major double membrane organelle found in plant cells. Plastids are the sites of manufacture and storage of important chemical compounds used by the cell. They often contain pigments used in photosynthesis and many types of pigments that can change or determine the cell colour for different purposes. Plastids are classified into chloroplasts, chromoplasts and leucoplasts. All types of plastids are formed from a precursor molecule proplastids.

Chromoplasts:

These are pigmented plastids located in colourful (other than green) parts of plants like petals fruit covering. These plastids also help in cross pollination. These also contain chlorophyll but in very less amount.

> **Tit bits**
>
> *Most plants inherit plastids from one parent e.g., angiosperms inherit plastid from female gamete while many gymnosperms inherit plastid from male pollen.*

Leucoplasts:

These are colourless plastids present in colourless parts of plants like roots, woody stems etc. They are triangular in shape. They help in storage of food. e.g., **amyloplast** which stores starch, **Elaioplast** which stores lipids and **proteinoplast** which stores protein.

Chloroplast:

These are green plastids, present in green parts of plants like leaves, herbaceous stems, unripened fruits coverings etc.

They are double membrane structures. The outer membrane is smooth and more permeable while the inner membrane is less permeable. The inner membrane contains disc like structure called thylakoid and group of thylakoid stacked together is called **granum** (plural Grana). There are many grana in a chloroplast and many chloroplasts in a cell (up to 40). The fluid which surrounds grana is called **stroma.** The stroma contains enzymes required for the synthesis of carbohydrates during dark reactions of photosynthesis. The most abundant and important enzyme is

Rubisco (about 16% of chloroplast), stroma also contains small amount of DNA, RNA and 70s ribosome. Presence of these substances indicate that it is **semiautonomous** organelle of cell like mitochondria.

The grana are connected to each other by long thylakoid membrane called **lamellae.** The chloroplast is the site for photosynthesis. The light reaction takes place in grana which contains large number of photosynthetic pigment in an organized manner, while the dark reactions occur in stroma. It is believed that chloroplast originated from cyanobacteria through endosymbiotic process.

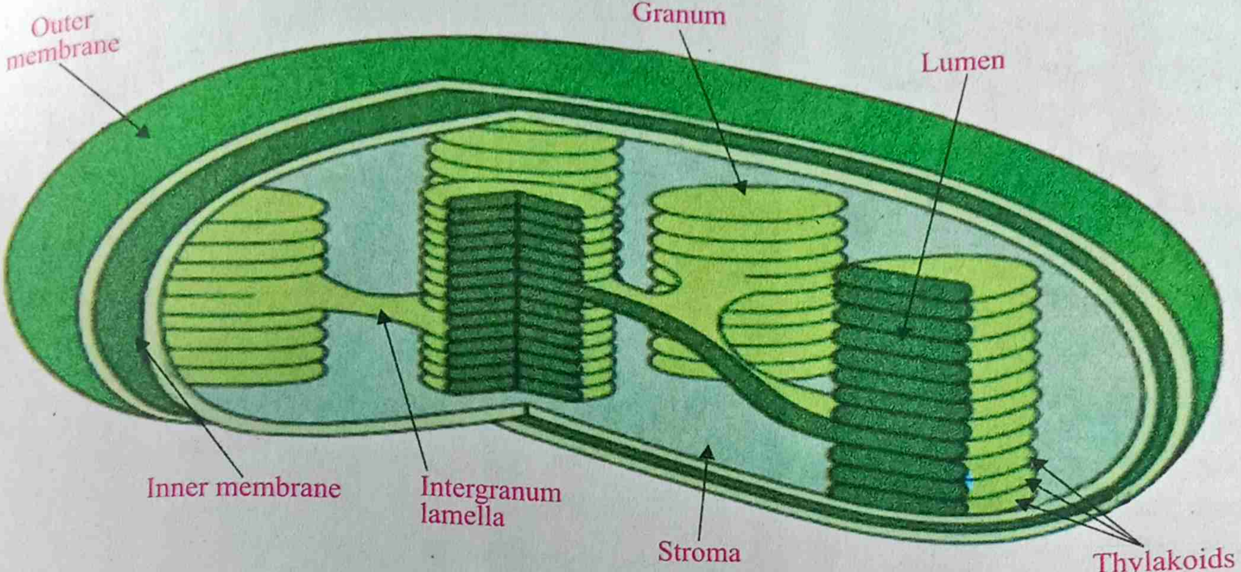


Fig. 1.15 Chloroplast

1.3.7 Cytoskeleton

The cytoskeleton (Gk: Kytos, cell ; Skeleton, dried body) are unbranched cylindrical structures which are made up of proteins and involved in internal structure, movement, contraction, relaxation, and maintain cell shape.

There are three types of cytoskeleton elements based on size and chemical composition, i.e., microtubules, microfilaments and intermediate filaments.

Microtubules:

These are small hollow cylinders, made of self assembling **tubulin protein**, 25nm in diameter. In plants microtubules often found associated with cell wall. Perhaps these are involved in the transport of cell wall materials from Golgi bodies to outside of the cell. During cell division, these microtubules form spindle fibers. Several cell organelles are also derived from special assemblage of microtubules e.g.,cilia, flagella, basal bodies and centrioles.

Microfilaments:

Microfilaments are considerably more slender, made up of contractile

protein called **actin** and linked to the inner face of the plasma membrane. These are about 7.0 nm in diameter and occur in bundles or mesh like network. Actin filament contains two chains of actin molecules twisted to each other. Besides the actin protein tropomyosin and troponin proteins also present.

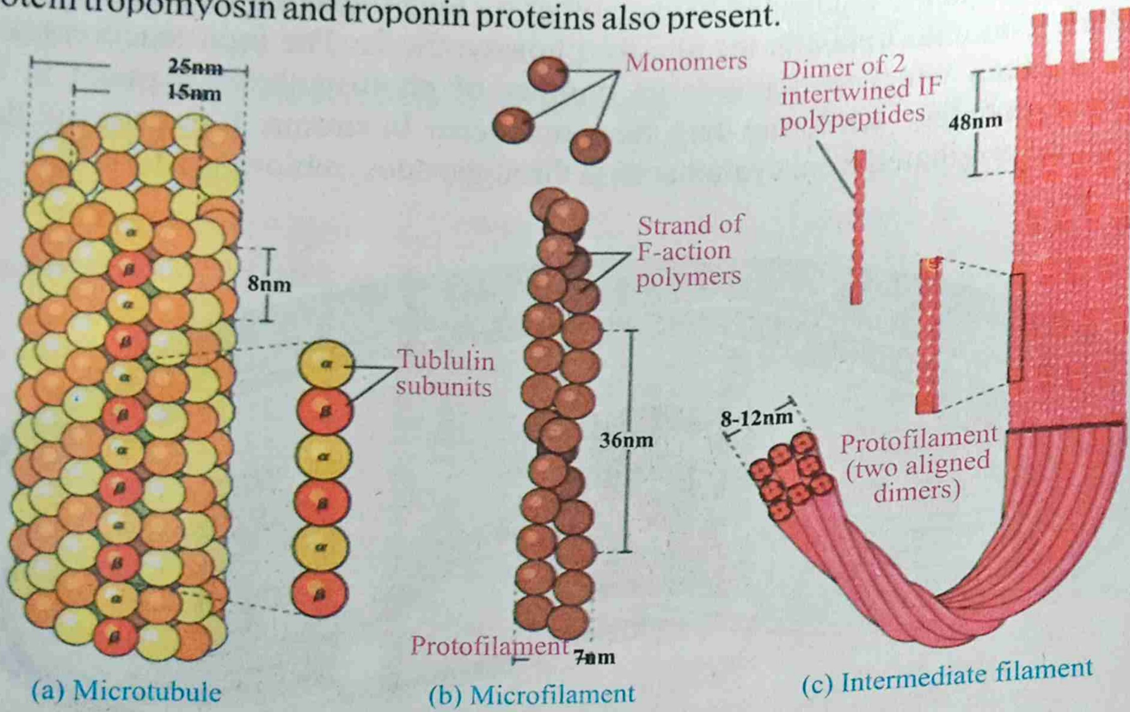


Fig. 1.16 Cytoskeleton

These perform functions of muscle contraction, change in cell shape including division of cytoplasm during cell division.

Intermediate filament:

These filaments are called intermediate because these are intermediate in size between microfilament and microtubule (about 8-12nm) in diameter. These are composed of **vimentin** protein. The intermediate filaments assemble and disassemble and, therefore, play important role in maintaining shape of cell, attachment of muscle cell, support of nerve cell processes i.e. axon.

1.3.8 Peroxisomes

It is a tiny single membrane bound cell organelle, which contain large amount of oxidative enzymes (such as peroxidase, catalase, de-amino acid oxidase, etc.).

These are spherical shaped organelle about 0.6 to 0.7μm in diameter. Their number varies between 70 to 100 per cell. It was first isolated by **De duve and co worker in 1965** in liver cells and other tissues which are rich with oxidative enzymes. It is also found in protozoans, yeasts and many higher plants.

Function

The name peroxisome was applied because this organelle is specifically involved in the formation and decomposition of hydrogen peroxide (H_2O_2) in the cell.

$$H_2O_2 \rightleftharpoons H_2O + \tfrac{1}{2} O_2$$

1.3.9 Glyoxisomes

These are cell organelles, mostly found in lipid rich seeds and seedling cells of plants. These contain enzymes like glycolic acid oxidase and catalase. Some other enzymes are also present which are involved in the conversion of lipids into carbohydrate by a process called glyoxylate cycle.

1.3.10 Centrioles

Centrioles are non-membranous organelles, two in number, located near the outer surface of nucleus. The diameter of centriole is 10nm. They are found in animal cells of some microorganisms and lower plants while absent in higher plants. Centrioles were **discovered by Beneden in 1883 and Boveri in 1895.**

Structure:

The cytoplasm which surrounds centrioles is called "centrosphere". Centrioles and centrosphere are collectively called centrosome. In cross section each centriole consists of a cylindrical array of nine microtubules. However, each of the nine microtubules is further composed of triplet tubules. Both centrioles are placed at right angle to each other.

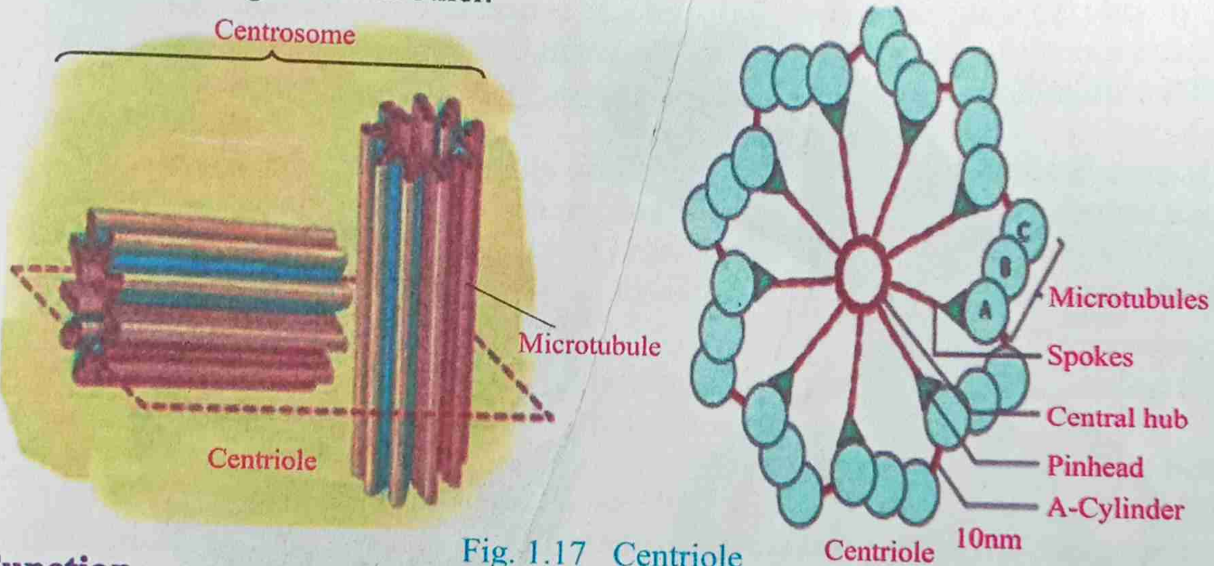


Fig. 1.17 Centriole

Function

They help in cell division. They are self replicating units and replicate just before the cell division. Each pair migrate towards opposite side of the nucleus. The spindle fibers are formed between

> **Tit bits**
>
> *Prokaryotic cells also have cytoskeleton which have same function but their structure is simple.*

these two pairs of centrioles. They play an important role in the location of furrowing during cell division and arrangement of microtubules.

1.3.11 Cilia and Flagella

Cilia (L. cilium, eye lash) and Flagella (L. flagella means whip) are hair like outgrowths of cell membrane and elongated appendages. They are present on the surface of some cells. They help in the movement of the cell. Some stationary cells also contain cilia (such as epithelial lining in respiratory system). The stationary cilia help in the movement of materials over the surface of the cell.

Flagella are five to twenty times longer than cilia. However, both cilia and flagella have same internal structure. They are membrane bounded **cylinders**. This membrane encloses a **matrix.** The matrix contains axonemes or axial filaments. The axonemes consist of nine pairs (doublets) of microtubules, which are arranged in a circle around two central tubules. This arrangement is called 9+2 pattern of microtubules. Microtubules slide over each other during movement of cilia and flagella. Each microtubules has two structures, the **dynein arms** which project towards the neighbouring doublets and

Do you know?

Basal bodies of cilia and flagella are types of centrioles.

Tit bits

Sperm centrioles are important for 2 functions. To form the sperm flagellum and sperm movement and in the development of embryo after fertilization.

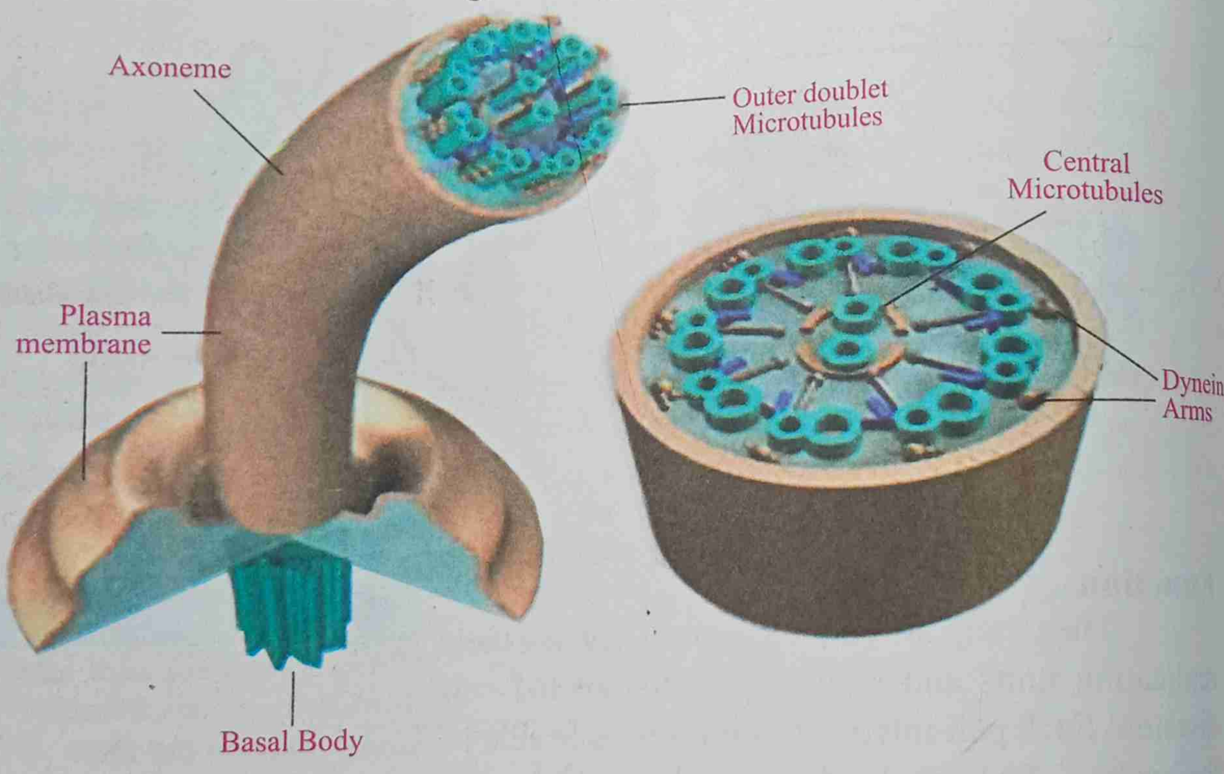


Fig. 1.18 Ultra Structure of Cilia and Flagella

spokes which extend towards the centre. Dynein have ability of hydrolysis of ATP and release energy for ciliary or flagellary movements. The flagella and cilia originate from the basal body (also called Kinetosome) which is modified form of centriole. Basal body controls the growth of cilia and flagella. Microtubules in the basal body form 9 + 0 (9 triplets) pattern. Basal body exhibits cartwheel structure.

Mechanism of movement:

Movement of these structures is due to the sliding of double fibrils into groups one after the other. (suggested by **Bradford**, 1955).

Effective stroke:

During effective stroke five out of nine double fibrils contract as a result cilium bends.

Recovery stroke:

During recovery stroke four out of nine double fibrils contract and make the cilium straight.

1.3.12 Nucleus (Greek. karyon= central commander)

Nucleus is a double membrane bounded cell organelle of eukaryotic cell. It was discovered by Robert Brown in 1831 in orchid cell. Nucleus controls all cellular metabolism and contains genetic information of the cell. Nucleus is considered as **controller** or **heart** or **brain** of the cell.

It is self replicating organelle, arises from division of pre-existing nucleus. Generally each cell contains one nucleus but sometime may be two to many, **dikaryote in *Paramecium*** and many in ***Opalina***. It is absent in some eukaryotic cells, such as in mature phloem sieve tube elements in plants and mature RBCs of most mammals.

In animal cells, it generally occupies the **central space** while in case of plant cells, it is pushed towards **periphery** due to the presence of a large central vacuole. It may be spherical, oval, elongated or irregular in **shape.** It is only visible when the cell is in non dividing stage. In dividing cells it disappears and chromatin material is replaced by chromosomes.

Structure: The nucleus of non dividing cell (inter-phase) consists of nuclear membrane, nucleoplasm, chromatin net and nucleolus.

Each nucleus is covered by two **parallel membranes** with a space between (10-50 nm) called the perinuclear space. It is composed of protein and lipid bilayer, like plasma membrane. The outer nuclear membrane is at places continuous with endoplasmic reticulum while inner nuclear membrane encloses the nuclear contents. The ribosomes are also attached to outer surface of nuclear membrane.

At certain points nuclear membrane is provided by **nuclear pores,** around the margins of these nuclear pores both membranes are fused with one another. These pores are also guarded by permeases in the form of a pore complex which

regulate RNA, ionic exchange (i.e., **nucleocytoplasmic traffic**) between nucleoplasm and cytoplasm. Nuclear membrane is also known as nuclear envelope.

Nucleoplasm: Nucleoplasm is ground substance of nucleus, which is also known as nuclear matrix or karyoplasm.

Chemical composition of nucleoplasm: It is a transparent complex colloidal form of solution or fluid contains water, protein and enzymes like ATPase, DNA and RNA polymerases, endonucleases. It also contains nucleotides and mineral ions (Ca^{++}, Mg^{++}) etc.

Nucleolus: Nucleoplasm also contains one or more nucleoli, which is non-membrane bound and spherical structure so that the content of nucleus is continuous with the rest of the nucleoplasm. Nucleolus usually attached to chromatin at specific site called nuclear organizer region (NOR). It is visible only during interphase while disappear during cell division.

It contains 85% proteins, 10% RNAs and 5% DNA.

The main function of nucleolus is to form sub units of ribosomes which move to cytoplasm by nuclear pore thus known as ribosome factory of the cell.

Chromatin net is network of nucleoprotein fibres, embedded in nucleoplasm. Chromatin fibres contain genetic information and condensed to form chromosomes during cell division.

Chemically chromatin consists of largely protein both histone (basic protein) and non histone (acidic protein), DNA and little amount of RNA.

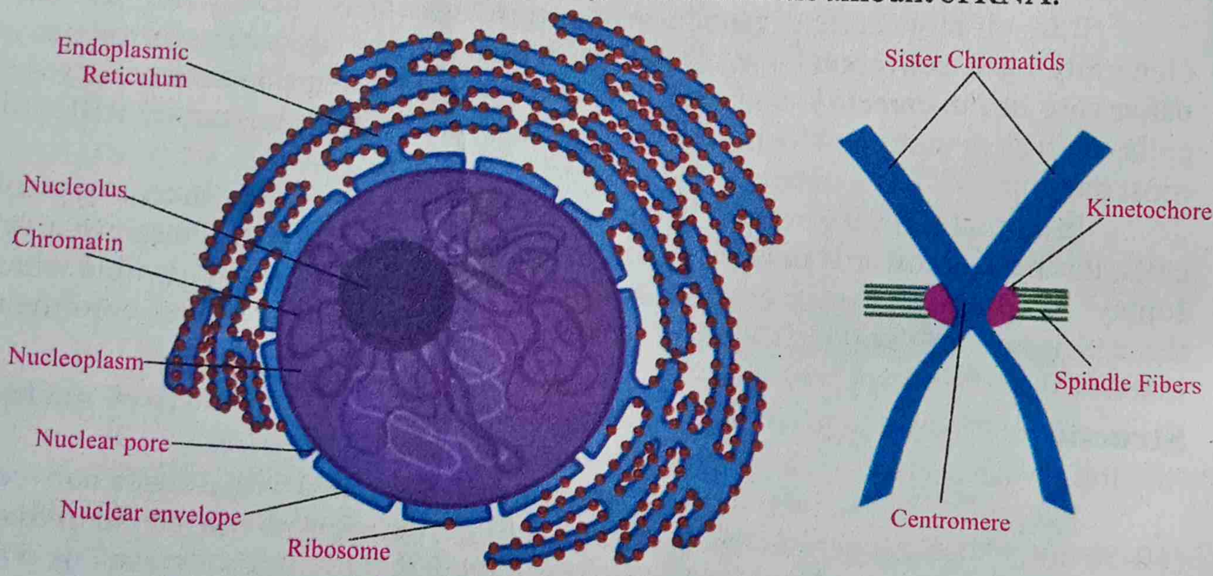


Fig. 1.19 Nucleus and Chromosome

Chromosomes (Greek - chromas : color, Soma: body)

Chromosome is highly condensed form of the chromatin, seen only during cell division. It often deeply absorbs basic dyes during staining thus darkly stained structure.

Chromosomes can be best studied at metaphase stage because size of chromosomes is the shortest during metaphase.

Karyotype

The number of chromosomes is definite for each species, for example in human, each body cell contains 46 chromosomes, Mucor (Fungs) 02, Pea 14, Maize 20, Frog 26, Chimpanzee 48, Fruit Fly 08, *Ascaris* (round worm) 02 etc. Each chromosome can be identified by its size and shape.

Structure of Chromosome

At metaphase stage, each chromosome consists of two identical (sister) cylindrical structures called chromatids. Both sister chromatids are connected together by a common centromere. Around the centromere is a disc of protein called kinetochore where spindle fibers get attached during cell division. Each chromatid is consist of a single long thread of DNA associated with histone and non-histone proteins, RNA is also present in it . Chromosomes are covered by thin proteinaceous sheath called pellicle. They are the vehicle of hereditary material (genes) from parent cell to daughter cell.

Do you know?

Which human cells do not possess nucleus and which cells are multinucleated?

1.4 Bacteria as a Model Prokaryotic Cell

Bacteria despite their simplicity, contain a well developed cell structure which is responsible for some of their unique biological structure. The cell wall is composed of **peptidoglycan** (murein) while in eukaryotes it is either composed of **cellulose or chitin.** Beneath the cell wall is cell membrane which lacks sterol such as cholesterol. Their plasma membrane contains respiratory enzymes. In many bacteria slimy capsule is present which is secreted by cell. Flagella are present in most bacteria which are chemically composed of **flagellin** protein. Many of gram -ve bacteria possess hollow proteinaceous filament known as pili. These pili are anchored in the membrane and project through the cell wall. They help in conjugation and attachment on the surface of tissues of the host. They are very thin, only visible under electron microscope and composed of **Pilin protein.** The cell membrane of some bacteria are folded into a structure called mesosome which help in respiration, photosynthesis and formation of new cross walls during cell division. The ribosomes of bacteria are small (70s) but numerous in number. Bacteria have **plasmids** which are small circular rings of DNA and contain genes for drug resistance, heavy metals and insects resistance. Some bacteria also have **transposons.** They are semi parasitic sequences of DNA that can replicate and spread through the host genome. They readily move from one site to another either within or between the DNAs, of bacteria, plasmid or bacteriophage.

Bacteria are haploid organisms, their single chromosome is present in the cytoplasm. That is not covered by nuclear membrane.

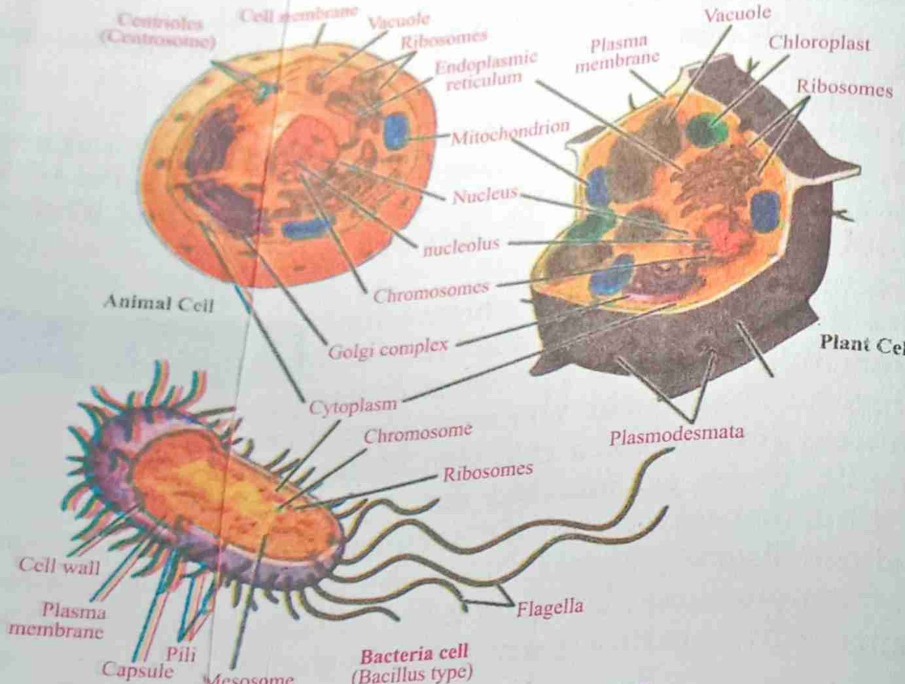


Fig. 1.20 Bacterial, Animal and Plant Cells

Table 1.4 Comparison between prokaryotic and eukaryotic cell

Prokaryotic cell (pro: before, karyon: nucleus)	**Eukaryotic Cell** (eu: true, karyon: nucleus)
• These cells have no prominent nucleus i.e., nuclear material is not bounded by nuclear membrane and nucleolus is also absent.	• These cells have distinct nucleus i.e., nuclear material is enclosed by nuclear membrane and nucleolus is also present.
• Found only in bacteria and cyanobacteria.	• Found in protists, fungi, plants and animals.
• Most membranous organelles are absent and double membrane organelles are not present.	• Most membranous organelles are present which are either covered by single or double lipo- proteinaceous membrane
• Mesosomes are present	• Mesosomes are absent
• 70s Ribosomes.	• 80s Ribosomes
• Single circular chromosome which is composed of only DNA	• 2 or more linear chromosomes are present which are mostly composed of DNA, Protein and little RNA.
• Cell wall contains Polysaccharide with amino acid (peptidoglycan)	• Cell wall is present either composed of cellulose (plants, algae) or chitin (fungi) and absent in animal cells
• Cell divides by binary fission i.e., no mitosis or meiosis.	• Cells divide by mitosis while germ line cells divide by meiosis.

Activity

Improve your knowledge by searching wikipedia and internet sources and make a list of different techniques used in study of structure of cell. Name the cell organelles that contain DNA. Trace the relationship between ribosome, endoplasmic reticulum, Golgi bodies and lysosomes.

Summary of Structures and functions of cellular components

Component	Structure / Description	Function
Centriole	Located within microtubule organizing center. Contains nine triplet microtubules.	Produces basal body of cilia and flagella; help in mitotic spindle formation.
Chloroplast	It possesses chlorophyll in Thylakoids and is involved in photosynthesis.	Traps, transforms, and uses light energy to convert carbon dioxide and water into glucose and oxygen.
Chromosome	Made up of nucleic acid (DNA) and protein and some RNA.	Controls cellular activities and carries genes.
Cilia, flagella	Both are thread like structures.	Cilia and flagella move small particles through fixed cells and their main role is chemotaxis.
Cytoplasm	Semi fluid enclosed within plasma membrane contains fluid cytosole; organelles and other structures.	Dissolves substances and contain suspended organelles and vesicles.
Cytoskeleton	Interconnecting microfilaments and microtubules; flexible cellular framework.	Help in cell movement; provide support; site for binding of specific enzymes.
Endoplasmic reticulum ER	Extensive membrane system extending throughout the cytoplasm from the plasma membrane to the nuclear envelope.	Storage and internal transport; rough ER is a site for attachment of ribosomes; smooth ER makes lipids and detoxification.
Golgi Apparatus	Stacks of disk and tubular shaped cisternae.	Secretion and packaging cellular substances.
Lysosome	Membrane bound sac like.	Digests polymer into monomer i.e. digestion.

Component	Structure / Description	Function
Microfilament	Rod like structure containing protein actin.	Gives structural support and assists in cell movement.
Microtubule	Hollow, cylindrical structure.	Help in movement of cilia flagella, and chromosomes; transport system.
Microtubule organizing center	Cloud of cytoplasmic material that contains centrioles	Dense site in the cytoplasm that gives rise to large numbers of microtubules with different functions in the cytoskeleton
Mitochondrion	Organelle with double, folded membranes, contains DNA, enzymes and coenzyme.	Convert energy into a form the cell can use (power house).
Nucleolus	Rounded mass within nucleus; contains RNA and protein.	Preassembly point for ribosomal subunits.
Nucleus	Spherical structure surrounded by a nuclear envelope; contains nucleolus, DNA and nucleoplasm.	Contains DNA that control cell's genetic program and metabolic activities.
Plasma membrane	The outer bilayer boundary of the cell; composed of protein, cholesterol, and phospholipids.	Protection; regulation of material movement; cell-to-cell recognition and gives shape.
Ribosome	Contains rRNA and protein; some are free, and some are attached to ER.	Site of protein synthesis.
Vacuole	Single membrane-bounded, sac in the cytoplasm.	Storage site of food and other compounds; also pumps water out of a cell (contractile vacuole while in plant non-contractile)
Vesicle	Small, membrane-bounded sac; contains enzymes or secretory products.	Site of intracellular digestion, storage, or transport.

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A. **Select the correct answer.**

1. Who observed nucleus in the cells of orchids under the microscope?
   (a) A.F.A. King (b) Robert Brown
   (c) Galileo (d) Henri Dutrochet
2. Robert Brown observed nucleus in 1831 in the cells of
   (a) Pea (b) Monkey
   (c) Orchids (d) Euglena
3. What is called the basic structural as well as functional unit of all living organisms?
   (a) Cell (b) Nucleus
   (c) Gland (d) Tissue
4. All cells arise from
   (a) Dead matter (b) Plants
   (c) Saprophytes (d) Pre-existing cells.
5. The function of an organism is the result of sum of activities and interaction of the
   (a) Neurons (b) Tissues
   (c) Muscles (d) Cells
6. Which type of cells can contract and relax?
   (a) Muscle Cells (b) Excretory Cells
   (c) Nervous Cells (d) Phloem Cells
7. Which type of cells transmit nerve impulses?
   (a) Muscle Cells (b) Nerve Cells
   (c) Nephron Cells (d) Xylem Cells
8. Which type of cells secrete hormones?
   (a) Tissues Cells (b) Muscles Cells
   (c) Respiratory Cells (d) Gland cells
9. Which of the following blood cells carry oxygen?
   (a) W.B.Cs (b) Platelets
   (c) R.B.Cs (d) Thrombocytes
10. In plants, which type of cells carry out photosynthesis?
    (a) Chlorenchymatous (b) Sclerenchymatous
    (c) Meristem cell (d) Collenchymatous

11. The modern technology enables us to isolate various components of cells including its organelles by a process known as
(a) Isolation
(b) Fractionation
(c) Centrifugation
(d) Fermentation

12. It is the outermost layer of the animal cell. It is thin, delicate, elastic and capable of limited self repair". This statement is true for which cell structure?
(a) Cell Wall
(b) Cell Membrane
(c) Nuclear Membrane
(d) Ribosome

13. Cell membrane allows some of the soluble particles to pass through but prevents others. This property is most appropriate to membrane which is
(a) Permeable
(b) Impermeable
(c) Selectively Permeable
(d) Semipermeable

14. In many animal cells the cell membrane helps to take in materials by infolding in the form of vacuoles. This type of intake is termed as
(a) Endocytosis
(b) Phagocytosis
(c) Pinocytosis
(d) Glycolysis

15. Which is called the ingestion of solid material through the cell membrane?
(a) Endocytosis
(b) Phagocytosis
(c) Pinocytosis
(d) Glycolysis

B. **Fill the blank spaces with suitable words.**

1. Borax carmine is an example of .... staining.
2. The term tissue culture was used by American pathologist ....
3. The discovery of cell was directly related with the invention of the ....
4. The cell is the unit of function and structure of ....
5. Magnification power of microscope depends on ....
6. Group of ribosomes attached to mRNA is known as ....
7. Ribosomes are synthesized in ....
8. The factory for protein synthesis is the ....
9. Secretory and packaging organelle of cell is called ....
10. Glyoxisomes are the most abundantly found in ....
11. Microfilaments are composed of contractile ....
12. Mitochondrial infoldings are called ....
13. The inner surface of cristae in mitochondrial matrix has small knob like structure known as ....
14. Grana is the site for ....
15. Chromatids are held together at ....

- Explain the general structure of RNA.
- Distinguish in terms of structures and roles, the three types of RNA.
- Define conjugated molecules and describe the roles of common conjugated molecules i.e. glycolipids, glycoproteins, lipoproteins and nucleoproteins.

Introduction

Biological molecules are present in living organisms such as proteins, carbohydrates, lipids, nucleic acids. The study of biological molecules, their processing and significance for living organisms is called to as **Biochemistry.** The knowledge of Biochemistry is important in many ways for example, to understand the working of biological systems, development in agriculture, pharmaceutical industries, food industries and more importantly for the expansion of field of genetics and biotechnology.

2.1 Biological Molecules in Protoplasm

All the matter of universe contains more than 100 elements although living organisms are composed of 25 elements, yet only 16 of these are essential for life. Six most common elements in all living organisms are hydrogen, carbon, oxygen, nitrogen, sulphur and phosphorous.

They account for about 99% of total mass of living organisms.

Do you know?

Protoplasm is the living content of the cell that is surrounded by a plasma membrane. It is a general term for cytoplasm and nucleoplasm.

Biological importance of hydrogen oxygen, nitrogen and carbon is largely due to their valencies having one, two, three and four respectively and their ability to form more stable covalent bond than any other element with same valencies.

Table 2.1 Approximate Chemical Composition of a Mammalian Cell

Water	70%
Protein	18%
Carbohydrate	4%
Lipids	3%
DNA	0.25%
RNA	1.1%
Other organic substances	
Enzymes, Hormones etc.	2%
Inorganic ions	1%

Table 2.2 Approximate Percentage of Bioelements in human body

Oxygen	65%
Carbon	18.5%
Hydrogen	9.5%
Nitrogen	3.3%
Calcium	1.5%
Phosphorus	1%
Potassium	0.4%
Sulphur	0.3%
Sodium	0.2%
Chlorine	0.2%
Magnesium	0.1%
Trace elements (14 types) less than	0.01%

Do you know?

The six most abundant elements in human body are oxygen, carbon, hydrogen, nitrogen, oxygen, calcium and phosphorus.

In biochemistry, **trace elements** are dietary elements that are needed in a very minute quantity for proper growth, development and functioning of the organism. Examples of trace elements are:

Copper, Boron, Chromium, Iodine, Zinc, Iron, Manganese, Cobalt, Fluorine, Silicon, Vanadium, Molybdenum, Tin and Selenium.

Macro-organic molecules:

There are four types of macro organic molecules in living things. These are proteins, carbohydrates, lipids and nucleic acids.

Do you know?

Macromolecules are made from many repeating units i.e., polymers and have higher molecular weight, while Micro molecules are individual units of polymers and have low molecular weight.

Protein are the most abundant organic compounds in protoplasm. Basic units of proteins are amino acids. Proteins are present in different forms like enzymes, hormones, antibodies etc. These are building materials of life.

Carbohydrates are composed of C, H, O and provide fuel for the metabolic activities of the cell, also store reserve food in cell.

Lipids are heterogenous groups of hydrophobic compounds, which act as reserved food stored and building material for cellular organelles.

Nucleic acids (DNA and RNA) are most essential organic compounds, for living organisms, their basic unit is nucleotide. DNA acts as hereditary material, while RNAs synthesize proteins under the instruction of DNA.

Main Metabolic Reactions in a Cell:

Condensation:

Specific small molecules when join together they form large molecule or

polymers. This process is called condensation, in which water is produced, while energy is used. During condensation, when two monomers join, an **OH^-** is removed from one monomer and **H^+** is removed from the other. The condensation is also called dehydration synthesis.

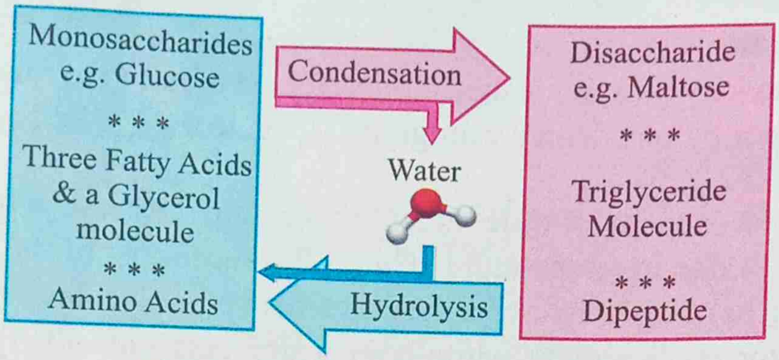


Fig. 2.1 Condensation and Hydrolysis

Hydrolysis:

Usually means the breakdown of polymer into monomers. In this process water is used, one monomer gets H^+ and other OH^- ion with the help of enzymes. When a bond is broken, energy is released. This process is also known as hydration.

2.2 Biological Importance of Water

Water is the most abundant component of protoplasm, with out it, life can not exist. It is important for different reasons; Such as vital chemical constituent of living cells and secondly it provides an environment for those organisms that live in water. The bodies of living organisms contain about 70-90% of water. Water has following important properties.

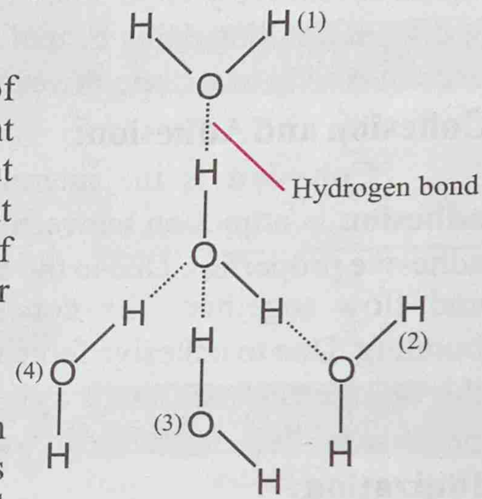


Fig. 2.2 Hydrogen bond

High Polarity:

Water is a polar molecule because its hydrogen contains slightly positive charge and oxygen contains slightly negative charge. A polar covalent bond is formed between hydrogen and oxygen atoms of water. Due to this polar covalent bond water is called polar molecule and thus it is universal solvent for polar substances, ionic compounds or electrolytes. The non-polar molecules having charged groups on their molecules can also be dissolved in water like sugar.

Do you know?

Bone contains only 20% water while brain 85% and blood 88%. The body of jellyfish contains 99% of water.

Hydrogen Bonding:

Hydrogen bond is electrostatic attraction between two polar groups that occurs when an hydrogen atom covalently bond to a highly electronegative atom such as oxygen, nitrogen and fluorine.

Due to hydrogen bonding water has a specific boiling and freezing point. (Boil at $100^{\circ}C$ and freezes at $0^{\circ}C$). The boiling and freezing point of water is important to sustain life on earth.

High Specific Heat:

The heat capacity of water is the amount of heat required to raise the temperature of one gram of water by one degree centigrade ($15^{\circ}C$ to $16^{\circ}C$), i.e., one calorie or 4.18 joules .

The high heat capacity of water means that a large increase in heat energy results in a relatively small rise in temperature. This is because most of the energy is used in breaking hydrogen bonds which restrict the movement of molecules. Due to this property of water, hot water cools slowly while cool water gets hot slowly. As a result the temperature of earth and living bodies does not change quickly and environment remains stable.

High Heat of Vapourization:

High heat of vapourization is a measure of the heat energy required to vapourize a liquid. A relatively large amount of energy is needed to vapourize water. This is due to hydrogen bonding. High heat of vapourization is useful for animals and plants to get rid of excess body heat during sweating, panting and transpiration etc.

Cohesion and Adhesion:

Cohesion is the intermolecular attraction between similar molecules while **adhesion** is attraction between dissimilar molecules. Water exhibit both cohesive and adhesive properties. Due to the cohesion water molecules stick together, remain in liquid and flow together. The cohesion is due to hydrogen bonding. Due to adhesive force water stick with the wall of the container (such as in xylem wall). This property is because of the polar nature of water.

Ionization:

It is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons to form ions. On ionization water releases equal number of **H** and **OH** ions. The state of equilibrium is maintained at $25^{\circ}C$.

Hydrophobic Exclusion:

It is the reduction of the contact area between water and hydrophobic substances when placed in water. This property of water plays an important role in maintaining the integrity of lipid bilayer of all plasma membranes.

Tit bits

The heat of vapourization of water is 574 kcal/kg and evaporation of only 2ml out of one liter of water, lowers the temperature of remaining water by $1^{\circ}C$.

Tit bits

The part of compound that reacts with an other compound is called functional Group e.g., Hydroxyl Group, Keto Group, Aldehyde Group and Corboxyl Groups.

Density and Freezing Properties:

The density of water decreases below $4^\circ C$, therefore, ice is lighter than water, and tends to float. It is the only substance whose solid form is less denser than its liquid, because it has maximum hydrogen bonds. Ice insulate the water below it thus increases the chances of survival of organisms during winter.

2.3 Carbohydrates

These are organic compound, containing the elements of Carbon, Hydrogen and Oxygen in the ratio of 1:2:1. Their general formula is $\mathbf{C_x(H_2O)_y}$, where **x** and **y** are variable numbers. Carbohydrates are also known as hydrated carbon because the number of hydrogen and oxygen atom is same as in water.

Chemically they are polyhydroxy aldehyde or ketone or complex substances.

Their chemistry is determined by aldehyde and ketone group e.g. aldehyde are very easily oxidized and hence are powerful reducing agents. Carbohydrates are commonly called sugars or saccharides.

> **Tit bits**
>
> *Water is effective lubricant, prevent friction e.g. Tears protect the surface of eyes, from rubbing of eye lids, act as cushion around many organs (cerebro spinal fluid around central nervous system and amniotic fluid around foetus prevent from trauma).*

> **Do you know?**
>
> *The source of carbohydrates are green living things (e.g. Plants cyanobacteria, algae and many bacteria).*

Classification:

There are three main classes of carbohydrates, that is monosaccharide, Oligosaccharide and polysaccharide.

Monosaccharide: (Gk. Mono: one, Saccharide: sweets or sugar)

They are simplest form of carbohydrates which cannot be hydrolyzed into simple units. The monosaccharides are small organic compounds made up of one sugar molecule, containing 3 to 7 carbon atoms.

They are very sweet in taste and easily soluble in water. All carbon atoms in a monosaccharide except one have a hydroxyl group while the remaining carbon either contain aldehyde or ketone. The sugar with aldehyde group is called aldo sugar and with ketone group is called keto sugar. Specific formula for monosaccharide is $C_n(H_2O)_n$ where, n is the number of carbon atoms in monosaccharides.

> **What are Vitamins?**
>
> *Any of various organic substances that are essential for normal growth and nutrition. They are needed in minute quantities in the diet, act especially as coenzymes and precursors of coenzymes in the metabolic process but do not provide energy or serve as building unit. These are present in natural food stuffs or some times produced within body.*

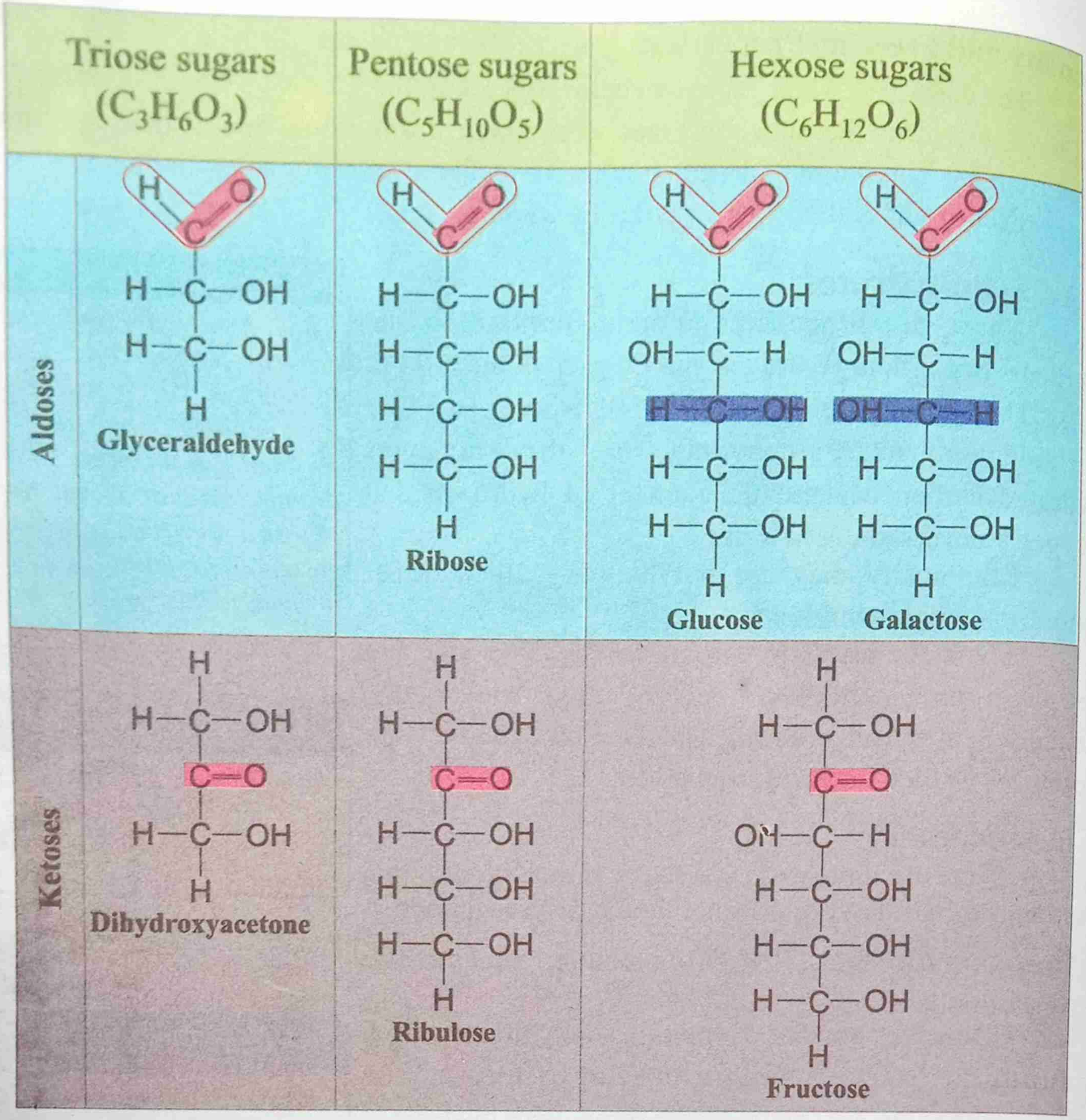


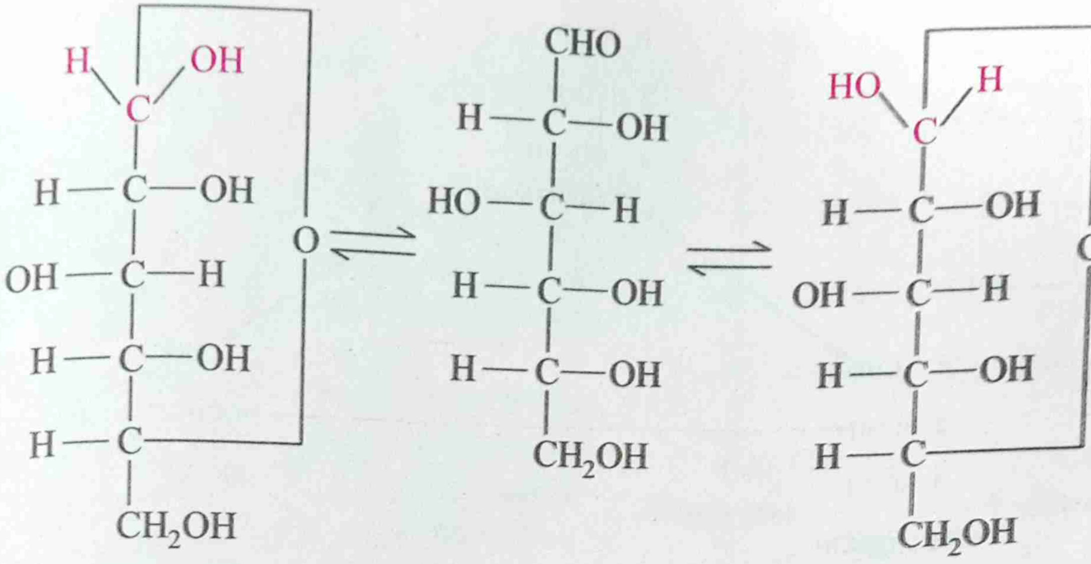
Fig. 2.3 Monosaccharides

Molecular and structural formula:

The molecular formula for a hexose is written as $C_6H_{12}O_6$. It is useful to show the arrangement of atoms in a molecule by a diagram which is known as structural formula.

Ring structure:

Pentoses and hexoses usually form rings in water. In pentoses and hexoses the chain of carbon atom is long enough to close up on itself and form a stable ring structure e.g. glucose. When glucose forms a ring, carbon atom No.1 joins to the oxygen on carbon atom No.5. The ring, therefore, contains oxygen and the last carbon of glucose is not part of ring.



Alpha D-glucose　　Aldehyde form (free CHO)　　Beta D-glucose

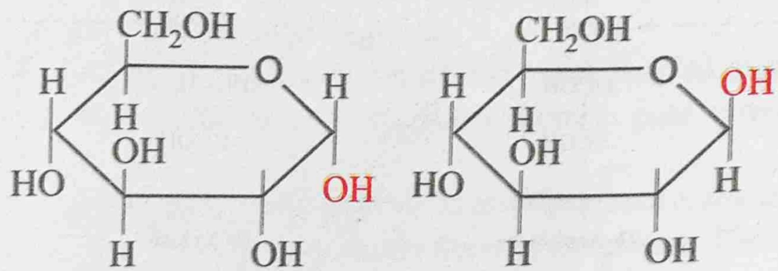


Fig. 2.4 Linear and ring forms

The hydroxyl group, (OH) on carbon atom number one may be above or below the plane of ring. If it is below the ring is known as alpha glucose (α -glucose) and if it is above then known as β-glucose (Beta glucose). The two different forms of same chemical is known as isomer.

Trioses:

Their formula is $C_3H_6O_3$ for example glyceraldehyde, dihydroxy acetone. These are intermediate substances in cellular respiration and photosynthesis.

Pentoses:

Their formula is $C_5H_{10}O_5$ e.g. ribose, deoxyribose and ribulose. Ribose is the component of RNA, ATP, NAD,.FAD, NADP etc. Deoxyribose is the component of DNA while ribulose is the component of RUBP which is the CO_2 acceptor in photosynthesis.

Hexoses:

Their formula is $C_6H_{12}O_6$ e.g., glucose, fructose, galactose. Glucose is the most common respiratory substrate and also most common monosaccharide.

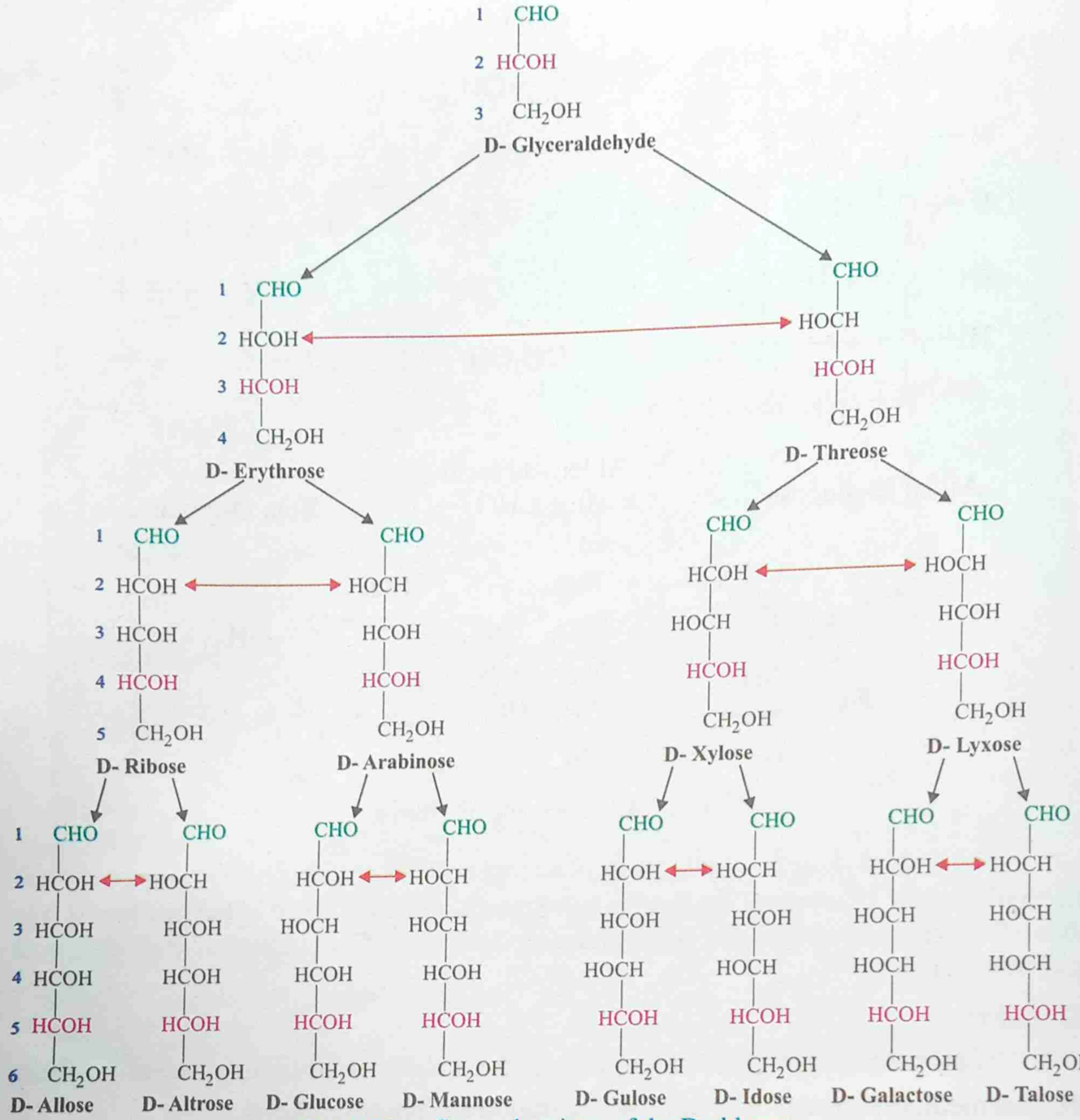


Fig. 2.5(a) Stereochemistry of the D-aldoses

Comparison between Structural Isomers and Stereoisomers:

Isomers (Gk. Iso: equal, meros: part) are molecules with the same molecular formula but different chemical structure. It means that isomers contain same number of atoms of each element but have different arrangements.

Isomers do not generally share similar properties,

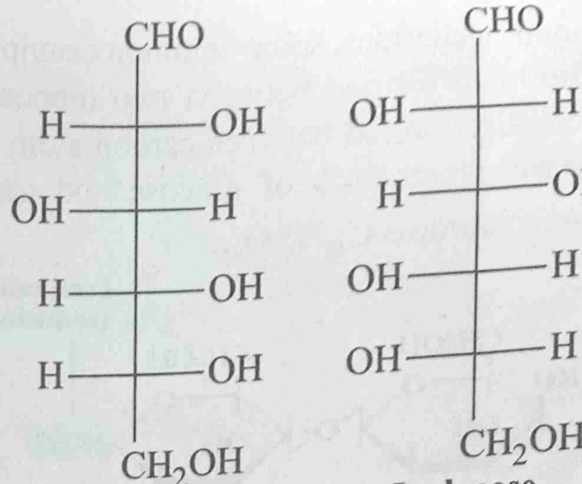
Activity

Can you justify that laboratory manufacturing sweetners are the left handed sugar and cannot be metabolized by the right handed enzyme.

unless they also have same functional group. There are two main forms of isomerism, the structural isomerism and stereoisomerism.

In **structural isomers** (also called constitutional isomers) the atoms and functional groups are joined together in different ways, glucose and fructose are structural isomers.

In **stereo-isomerism** the bond structure is the same but the geometrical positioning of atom and functional groups in space differs e.g., **D-glucose** and **L-glucose.**



D-glucose **L-glucose**

Fig. 2.5(b)

The Laboratory Manufactured Sweeteners are "Left - handed" Sugars:

Two forms of chemical compounds may exist, that are mirror image of each other. A suitable analogy is pair of gloves, they can be either left handed or right handed. Sugar are also left handed and right handed molecules.

Our digestive enzymes can only digest the right handed sugar molecules but generally do not digest the left handed and allow them to pass through body without digestion.

The LH sugar have same physical properties as D-glucose, therefore, may be used instead of D-glucose e.g., for baking and also making ice cream. The left-handed sugar are not commonly used because they are expensive, not commonly available and their over use cause serious disturbance for diarrhea patients. The laboratory manufactured sugar such as tagatose, sucralose etc. are examples of LH sugar. These sugar molecules can not be digested because mostly the enzymes for their digestion are not synthesized in the body and our cells do not have receptors for them. LH sugar are not converted into fats.

Oligosaccharides:

They are made up of 2 to 10 monosaccharides. Some examples of oligosaccharides are Disaccharides, Trisaccharides, Tetrasaccharides. The most common oligosaccharides are disaccharides.

Disaccharide:

It is made up of two monosaccharide (usually hexoses) combine by means of chemical reaction known as condensation.

Disaccharides are less sweet in taste and less soluble in water as compared to monosaccharides.

Disaccharides on hydrolysis give two

Tit bits

Malting is the process of converting of barley or other cereal grains into malt for use in brewing, distilling. This process takes place in malt house or malting floor.

monosaccharides, some common examples are maltose, lactose, sucrose and cellobiose. The bond formed between two monosaccharide is called glycosidic bond and it is normally formed between carbon atom 1 and 4 of neighbouring unit while in sucrose between carbon 1 of glucose and carbon 2 of fructose. The general formula of disaccharide is $C_{12}H_{22}O_{11}$.

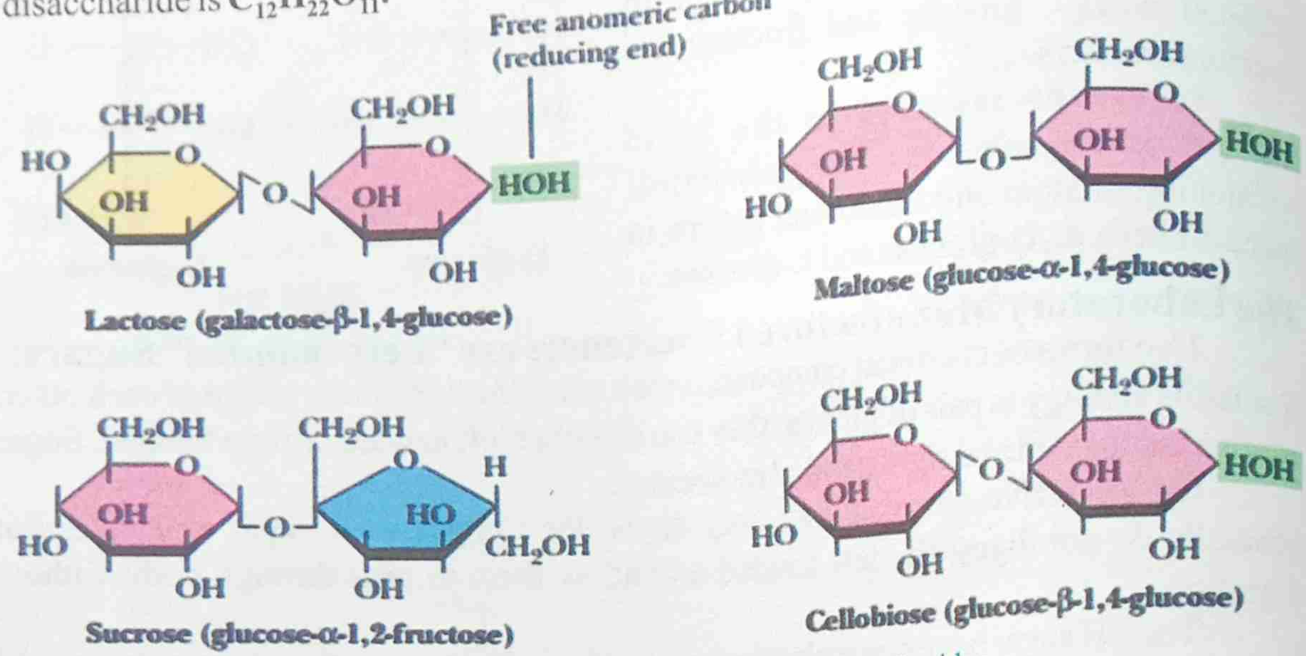


Fig 2.6 Structures of several common disaccharides.

The Role of Disaccharides:

Maltose is a disaccharide found in fruits and also found in our digestive tract as a result of breakdown product during digestion of starch by enzyme called amylase. It is also used in brewing industries to synthesize alcohol.

Lactose is milk sugar and it is an important energy source for young mammals. The **sucrose** or cane sugar is the most abundant disaccharide in nature and is hydrolyzed into glucose and fructose. It is obtained commercially from sugar cane or sugar beet, the sugar we normally buy in shops. All monosaccharides and some disaccharides including maltose and lactose are reducing sugars because these sugars can carry out a type of chemical reaction known as reduction. Sucrose is the most common non reducing sugar.

Tit bits

Starch gives blue color when treated with iodine and gives many molecules of glucose on hydrolysis.

Tit bits

Glycogen gives a red color when treated with iodine while cellulose does not show any reaction with iodine thus does not give color.

Polysaccharides:

Polysaccharides exhibit following properties. They are made up of several

monosaccharide, linked by glycosidic linkage may be branched or unbranched. They are tasteless and insoluble or some time sparingly soluble in water. They are most abundant in nature. Their general formula is $C_x(H_2O)_y$.

Types of polysaccharide:

Important polysaccharides are starch, glycogen, cellulose, dextrin, agar, chitin, pectin. All the above polysaccharides function chiefly as food, energy storage and structural material.

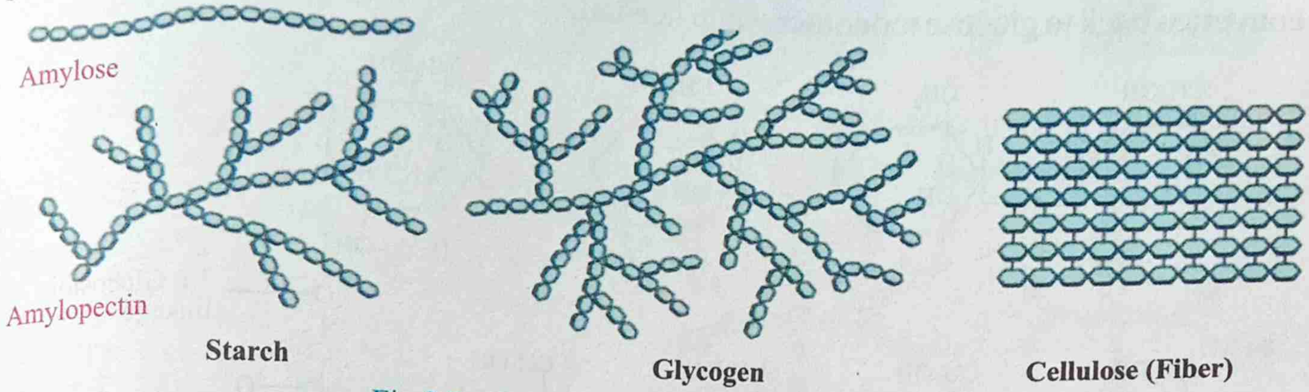


Fig.2.7 Different types of polysaccharides

Starch:

Starch is the polymer of glucose. It is major fuel store in plant and main source of food for animals. There are two types of starches, the simplest form is **amylose,** which has straight chain structure and joined by 1-4 **glycosidic** linkage. The other form is **amylopectin** which is more complexed and branched polymer with 1-6 linkage at branched point. Amylose is soluble in warm water but insoluble in cold water due to its simple structure while amylopectin is neither soluble in warm nor in cold water.

Cellulose:

It is a polymer of glucose and the most abundant carbohydrate in nature, unlike starch and glycogen it has structural role and main constituent of cell wall of plants and

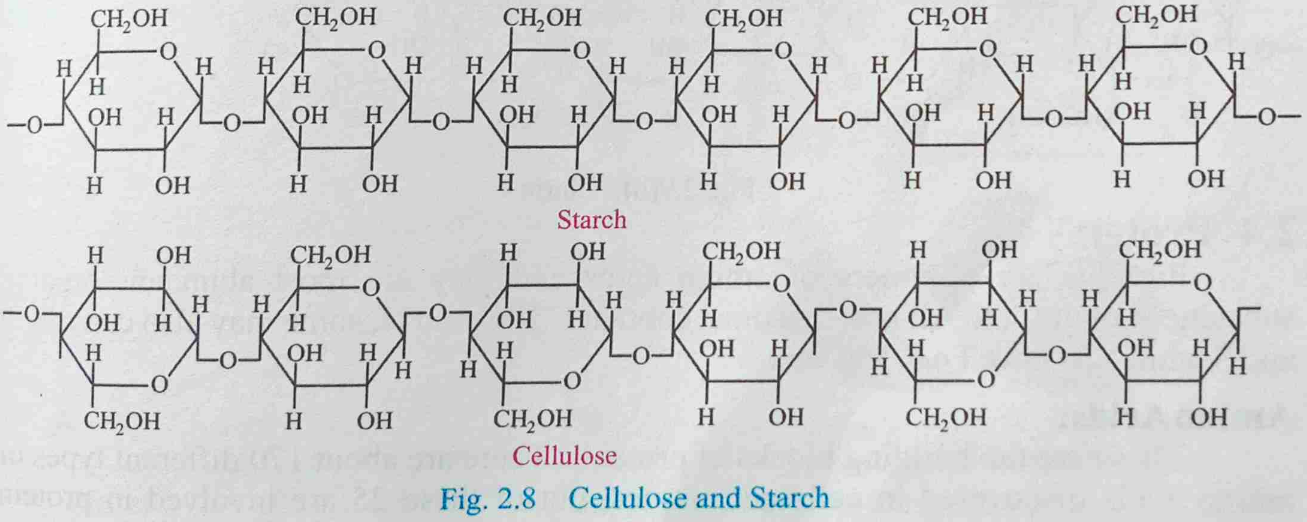


Fig. 2.8 Cellulose and Starch

algae. Cellulose is highly insoluble in water and we can not digest it because we do not have cellulase enzyme. However, herbivores can digest it because their digestive tract contain micro-organisms like bacteria, yeast, protozoans which secrete cellulase enzyme.

Glycogen:

It is a polymer of glucose and also called as animal starch. It is stored in liver and muscles. It is also found in fungi. It is insoluble in water due to complex structure and converted back to glucose monomer when needed.

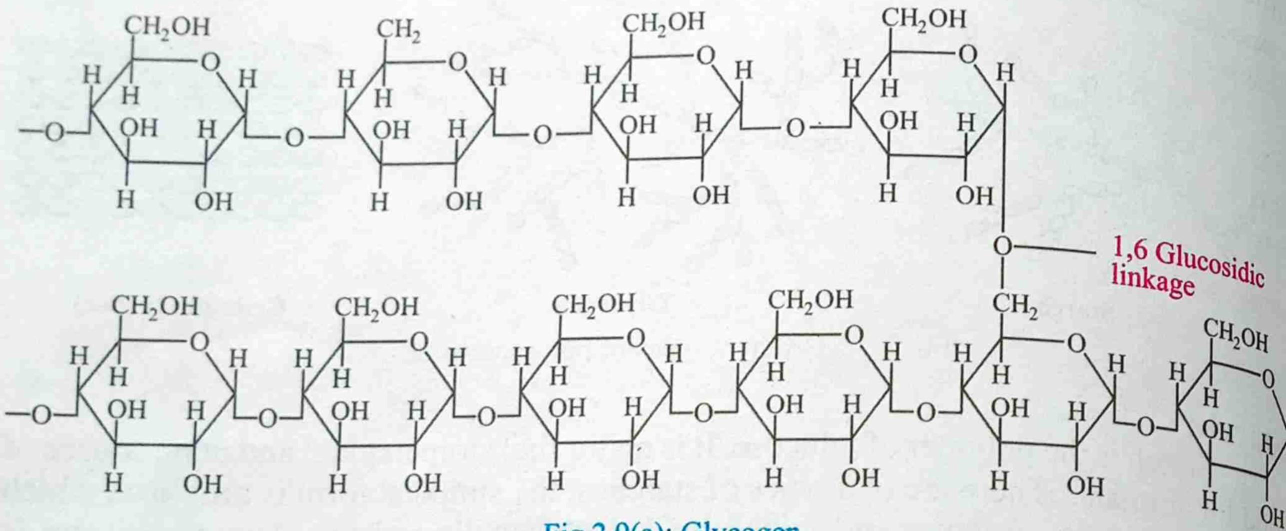


Fig.2.9(a): Glycogen

Chitin:

It is the structural nitrogenous polysaccharide and closely related to cellulose, found in cell wall of fungi and exoskeleton of arthropods.

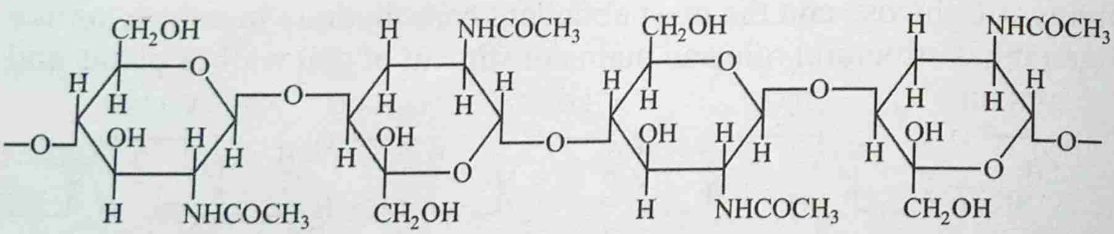


Fig. 2.9(b): Chitin

2.4 Proteins

Proteins are polymers of amino acids and they are most abundant organic substances in the cell. All proteins must contain C,H,O and N, some may also contain, P and S while few have Fe, I, Mg^{+} etc.

Amino Acids:

These are the building blocks of proteins. There are about 170 different types of amino acids discovered in cells and tissues, out of these 25 are involved in protein

synthesis. Most proteins, however, are made up of 20 types of amino acids. Each amino acid consists of an alpha carbon. On one side of this alpha carbon NH_2 (amino group) is present while on other side COOH (Carboxylic acid group) is present.

On the third side Hydrogen is present while fourth side radical group is attached which is different in all amino acids.

Many amino acids are non essential because body of the organisms can synthesize them, thus are mostly not required as dietary food. Few amino acids are essential because they are required in diet.

2.4.1 Peptide linkage

Amino acids are linked together to from polypeptide chain. The linkage between amino acids are called peptide or amide linkage. One or more polypeptide chains unite to form a protein molecule. The peptide linkage is formed by the condensation reaction between the amino group of one amino acid and the carboxyl group of another amino acid. Water is released during this reaction.

2.4.2 Significance of sequence of Amino acids

Each protein molecule is composed of unique and specific arrangement of 20 different types of amino acids. The sequence is determined by the order of nucleotides in the DNA. The arrangement of amino acids in a protein molecule is highly specific for its proper functioning. If any amino acid is not in its normal place, the protein fails to carry on its normal function. Best example is the sickle cell anemia disease of human beings. The

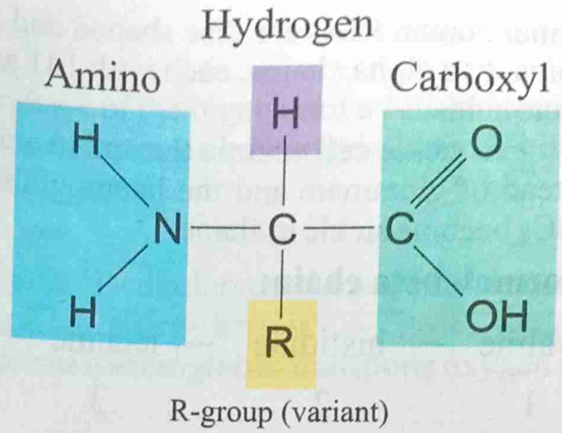


Fig. 2.10 An Amino Acid

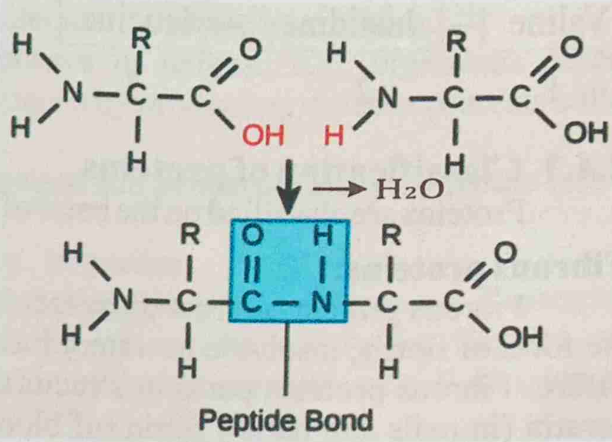


Fig. 2.11 A Dipeptide

Do you know?

Word protein has been derived from Greek word "proteios" which means prime or first.

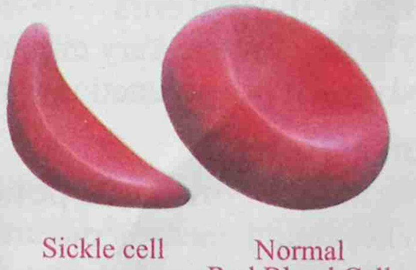


Fig. 2.12 Sickle cell anemia

normal human RBC are disc shaped and the haemoglobin consists of four polypeptide chains, two alpha chains, each with 141 amino acids and two beta chains each with 146 amino acids.

In sickle cell anemia the amino acid no. 6 of beta chain of haemoglobin is valine instead of glutamate and the haemoglobin fails to carry any or sufficient oxygen and RBCs become sickle in shape.

Normal beta chain:

Valine – histidine – leucine – threonine – proline – glutamate

1 2 3 4 5 6

G Replaced by V

↓

Sickle cell anemia:

Valine – histidine – leucine – threonine – proline – valine

1 2 3 4 5 6

2.4.3 Classification of proteins

Proteins are classified on the basis of their shape into two types.

Fibrous proteins:

Fibrous proteins consist of molecules having one or more polypeptide chains in the form of fibrils, insoluble in watery medium. They are non-crystalline and elastic in nature. Fibrous proteins perform structural role in cells and organisms. Examples are keratin (in nails and hairs) fibrin (of blood clot), myosin (in muscle cells), silk fibers (from silkworm and spider webs) and collagen (connective tissues of skin, bones, ligament, tendon etc).

Globular proteins:

Globular proteins are spherical or ellipsoid in shape. This shape is due to multiple folding of polypeptide chains. They are soluble in watery medium, such as salt solution, solution of acids or bases or alcohol and can be crystallized. They can be disorganized with changes in the physical and physiological environment. Examples are enzymes, antibodies, many hormones, haemoglobin and myoglobin etc.

2.4.5 Role of Proteins

The proteins are very important organic molecules of living organisms. They are involved in all types of function of body. Each protein has a specific function.

Structural Role:

Proteins as structural components:

They build many structures of the cell. All known structures, exclusively or predominantly composed of proteins. Bones, nails, hair, flesh and even blood of higher animals also contain huge quantity of proteins.

Proteins provide mechanical support:

Many structural proteins determine the shape of the organ or of a cell and provide mechanical strength that protect soft and delicate organs or cell organelles e.g., bones, collagen fibers and cytoskeletons.

Functional role:

Enzymes are proteins, work as biocatalysts, all cellular reactions are catalyzed by enzymes which decrease the energy of activation i.e., energy barrier.

Many proteins help in transportation, such as **haemoglobin** transports oxygen and CO_2 gases.

Myoglobin is another protein complex that stores oxygen in the red muscles. Protein molecules also store energy in muscles of the body which supply energy to the body when outside source of food is inadequate such as **phosphocreatine.**

Proteins also provide immune responses or defense e.g., organisms defend themselves from the harmful effects of pathogens by producing, defense proteins called **antibodies** with in their body.

Blood clotting proteins such as **fibrinogen** and **prothrombin**, prevent the loss of blood from the body after an injury.

Proteins also regulate metabolic processes e.g., **hormones.**

Contractility is one of the most outstanding property of proteins. Contractile muscle proteins **(actin and myosin)**. Tubulin of microtubule **(cilia, flagella** and centrioles) help in the movement of chromosomes during anaphase of cell division are caused by proteins **(spindle fibers).**

2.5 Lipids

The lipids are a heterogeneous group of organic compounds which are insoluble in water but soluble in organic solvents like alcohol, ether, chloroform, acetone, and benzene etc. Lipids have greasy or oily consistency and include the compounds like fats, oils, waxes, cholesterol and related compounds.

Like carbohydrates, lipids are also composed of C, H and O. However, the percentage of oxygen in lipids is less than the carbohydrates which makes lipids lighter and make it much less soluble in water than most carbohydrates.

Due to hydrophobic property lipids form the structures like membranes, act as storage compounds and possess double energy as compared to carbohydrates due to high proportion of C-H bonds.

2.5.1 Classification and role of lipids

As lipids are heterogeneous substances and made up of different building blocks. So lipids are classified on the basis of solubility and the products obtained upon hydrolysis. There are following main groups of lipids.

- Acylglycerol
- Phospholipids

- Terpenes
- Waxes

Acylglycerol: (Neutral fats):

They are esters of fatty acids and glycerol. They are most abundant form of lipids in living things. An **ester** is a compound produced as a result of chemical reaction of any alcohol with any acid and release of a water molecule. In case of acylglycerol alcohol is glycerol. Glycerol is three carbon compound having OH group attached with each carbon atom.

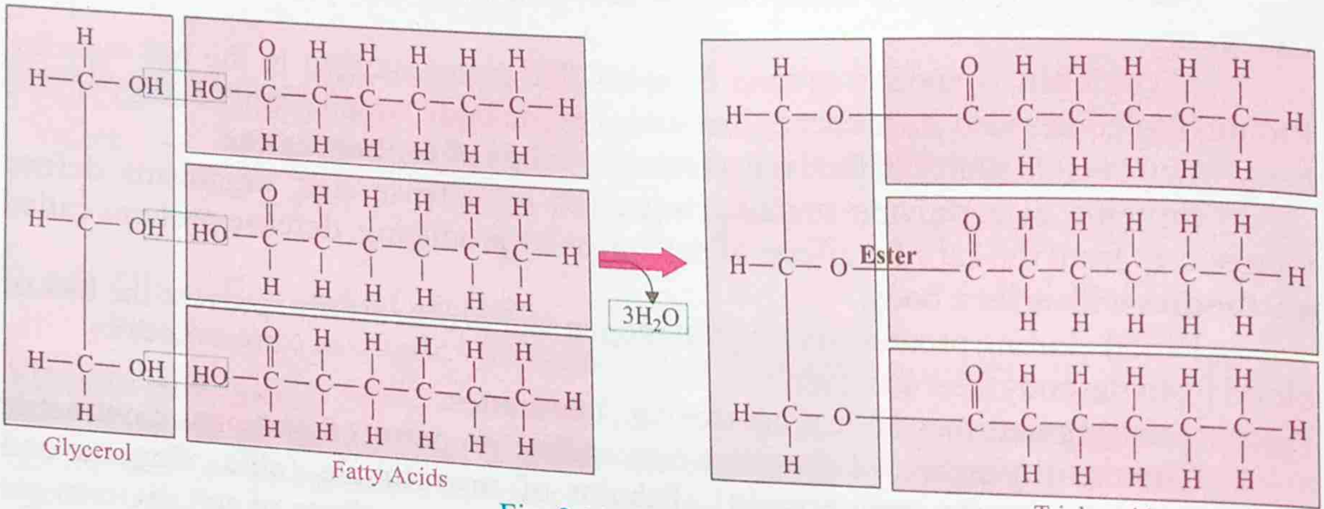


Fig. 2.13 Triglyceride

A fatty acid is a long straight chain of carbon atoms in even number (2-30) to which a carboxyl group is attached at the end. The acylglycerol may be in the form of monoglycerol, diglycerol or triglycerol depending on the number of fatty acids attached with glycerol. Triglycerol is most common among them.

There are about 30 types of fatty acids. These types of fatty acids vary in number of carbon atoms and bonds between carbon atoms (e.g., acetic acid 2 Carbons, stearic acid 18 Carbons).

A fatty acid may be **saturated** if it contains no double bond between carbon atoms or **unsaturated** if it contains 1—6 double bonds e.g. oleic acid.

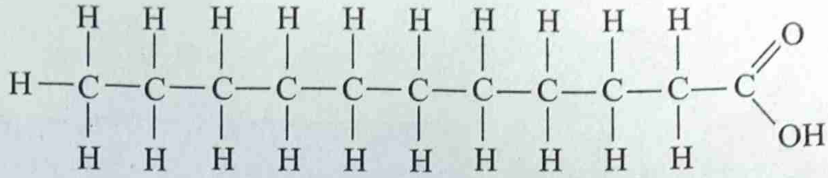
The saturated fatty acids are solid at room temperature, contain more energy due to high number of C—H bonds and mostly obtained from animals. On the other hand unsaturated fatty acids are liquid at room temperature, contain less energy due to less number of C—H bonds and usually obtained from plants.

Tit bits

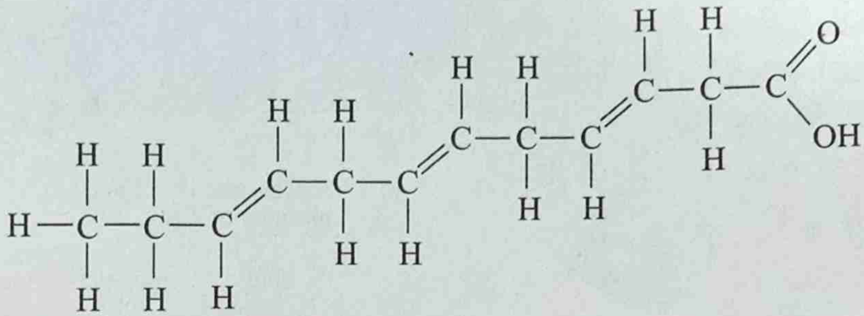
One gram of carbohydrate gives 4.1 Kcal, one gram of protein gives 4.6 Kcal while one gram of lipid gives 9 Kcal of energy.

Do you know?

Acylglycerol are called neutral fats because both acid and base are present in them.



Saturated Fatty Acid



Unsaturated Fatty Acid

Fig. 2.14 Saturated and Unsaturated Fatty Acids

Prostaglandins (PG):

The name prostaglandins is derived from prostate gland because it was first isolated from seminal fluid in 1935. It was believed to be part of prostatic secretions.

They are group of physiologically active lipid compounds having diverse hormone like effects in animals. Prostaglandins have been found in almost every tissue in human and other animals. They are derived enzymatically from fatty acids. Every prostaglandin contains 20 carbon atoms, including a 5 carbon ring.

In 1971 it was determined that aspirin like drugs could inhibit the synthesis of prostaglandin. The prostaglandins have a wide variety of effects such as cause dilation and contraction in smooth muscle cells, cause aggregation and disaggregation of platelets, regulate inflammation, regulate hormones, control cell growth, sensitize spinal neuron for pain, act on thermoregulatory center of hypothalamus to regulate fever etc.

Phospholipids:

Phospholipids are a class of lipids that are major components of all cell membranes. They can form lipid bilayers because of their **amphiphilic** characteristics. It`s molecule consists of 2 hydrophobic fatty acid tails and a hydrophilic head, consisting of phosphate group. The two components are joined together by a glycerol molecule. The phosphate group can be modified into nitrogenous organic compound such as choline, serine, ethanolamine etc.

> **Do you know?**
>
> ***Effects of too much fats in diet.***
>
> *Makes a person obese and also cause cardio vascular disorder like B.P, heart attack etc.*

In biological systems the phospholipids often occur with other molecules for example proteins, glycolipids, sterols and a bilayer such as "cell membrane". Lipid bilayers occur when hydrophobic tails line up against one another, forming a membrane of hydrophilic heads on both sides facing water.

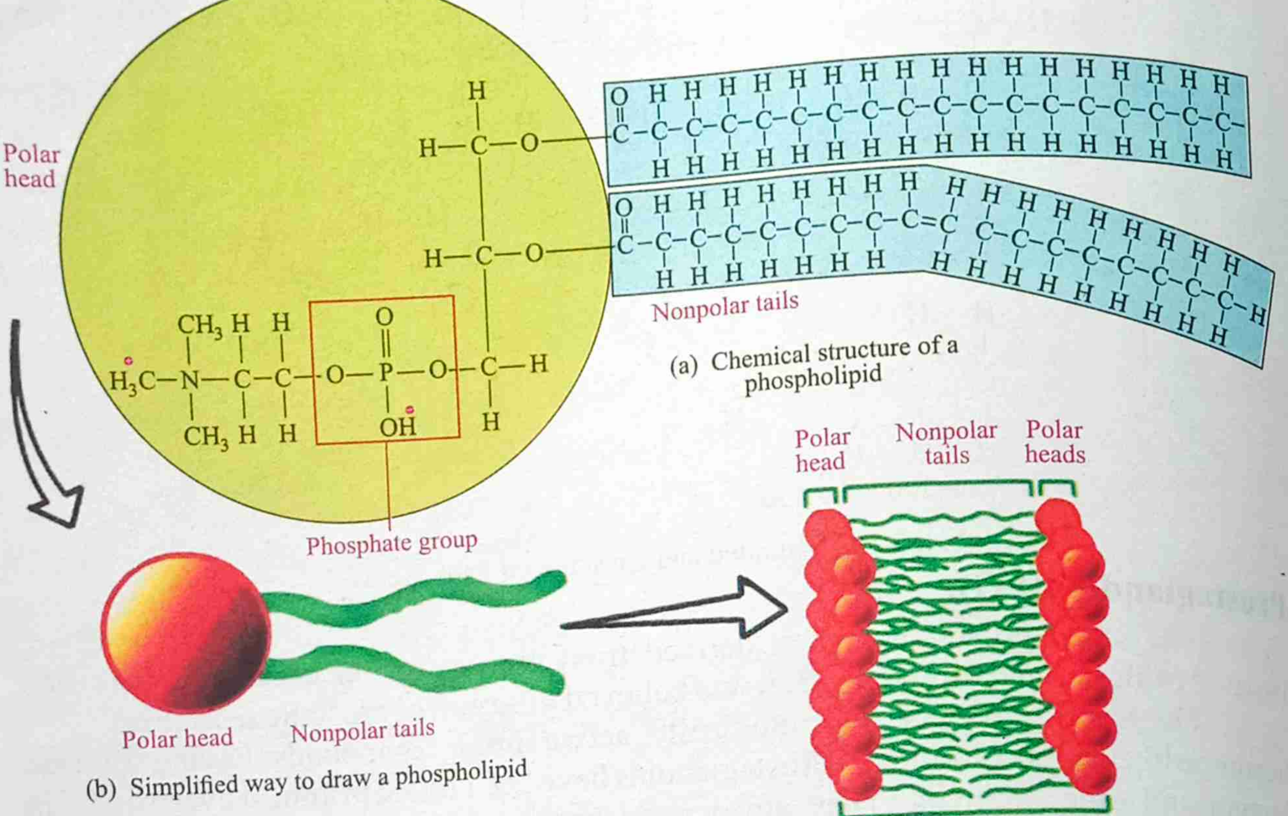


Fig. 2.15 Phosopholipid

Terpenes:

Terpenes are a large and diverse class of organic compounds, produced by a variety of plants and some insects. The building block of terpene is isoprene unit. This

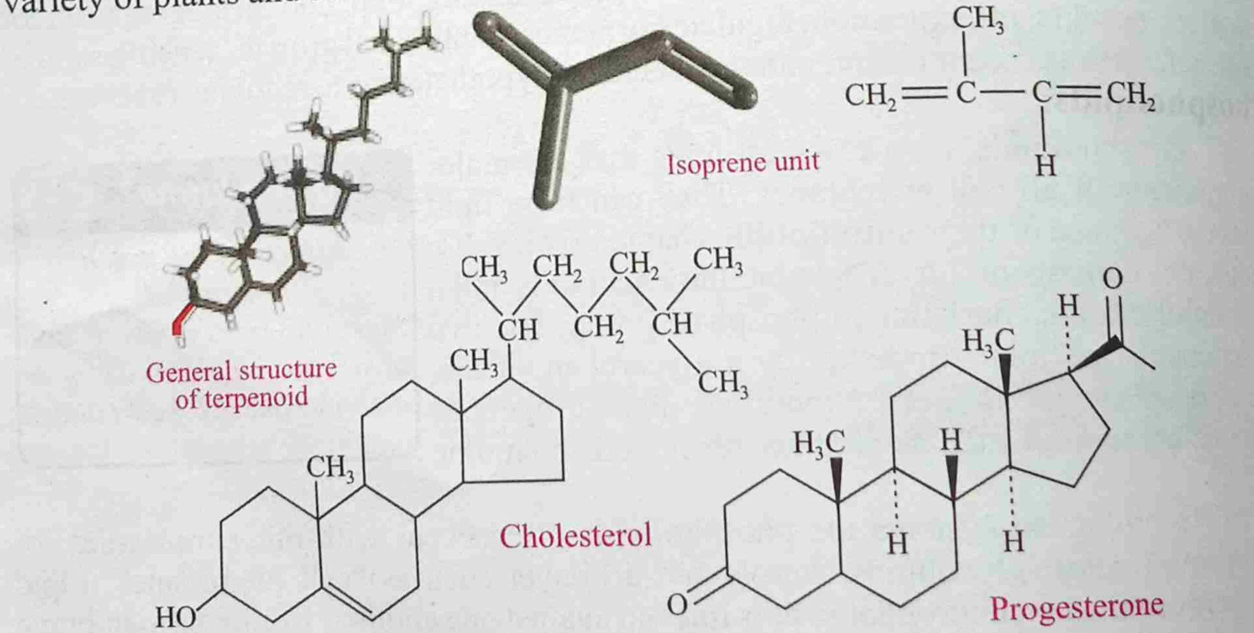


Fig. 2.16 Structure of Isoprene unit, Cholesterol and Progesterone

unit is condensed in different way to form many compounds. Two isoprene units join together to form a monoterpene $C_{10}H_{16}$ e.g., menthol and four isoprene units form a diterpene $C_{20}H_{32}$ e.g. vitamin A. Six isoprene units form triterpene $C_{30}H_{48}$ e.g., Ambrein, while rubber is a polyterpene.

Steroids:

Steroids are organic molecules and are included in lipids due to their similarities with other lipids. They are non fatty acid lipids. Their core structure is composed of 17 carbon atoms bounded in 4 interlocked rings. The first three rings are six sided while the fourth one is five sided. There are different types of steroids which vary by their functional groups attached to their four ring core.

Hundreds of steroids are found in plants, animals and fungi. All steroids are manufactured in cell.

Steroids play very important functions in the body. For example cholesterol is the structural component of cell membrane and brain tissue. Sex hormones like estrogen, progesterone in female and testosterone in male are steroids in nature. Vitamin D which regulates calcium metabolism and bile salts which emulsify fats are steroids.

> **Test your knowledge?**
> *Why the use of artificial steroids are banned in sports?*

> **Do you know?**
> *Synthetic prostaglandins are used to induce parturition, to prevent and treat peptic ulcer, to prevent egg binding, treatment of pulmonary hypertension etc.*

> **Do you know?**
> *Most common type of phospholipid is phosphatidylcholine also known as lecithin.*

Waxes:

They are organic compounds consist of long alkyl chain. They may also include various functional groups, fatty acids, alcohol, ketones and aldehydes.

Waxes are synthesized by many plants and animals. The most common animal wax is bee`s wax while in plants epicuticular waxes. They provide protection, act as water barrier, prevent abrassive damage etc. Cutin on leaves and fruits, suberin in plant roots are also examples of waxes.

> **Synthetic waxes**
> *Waxes are used in making:*
> - *Plastics*
> - *Candles*
> - *Coatings*

2.6 Nucleic Acids

Nucleic acids are the most important and essential group of complex organic substances in living things. They are polymers of nucleotides. The principal nucleic acids, DNA and RNA are the carrier of hereditary information and control synthesis of proteins.

Nucleic acid was first isolated in 1869 by a Swiss physician, Fredrick Miescher from the nucleus of pus cells and sperms of salmon fish. He named it as nuclein (because first recorded in nucleus), later their acidic nature was observed (due to the presence of phosphoric acid) and were named nucleic acids.

Jones in 1920 proved the fact that there are two types of nucleic acids, i.e. deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).

2.6.1 Chemical constituents of nucleic acid

As already described that nucleic acids are the polymeric organic molecules which are polymerized by the condensation of monomeric units called nucleotides. Nucleic acids despite their structural and functional diversity exhibit a constant chemical composition.

Structure of nucleotides:

The partial hydrolysis of nucleic acids yield compounds known as nucleotides or nucleosides while complete hydrolysis yields a mixture of bases, pentose sugars and phosphate ions.

DNA is made up of deoxyribonucloetides while RNA is composed of ribonucleotides.

Bases:

Base is a nitrogen containing heterocyclic organic molecule. There are two main types of bases in nucleic acids. i.e. pyrimidine and purine.

Pyrimidine Bases:

These consist of nitrogen containing six corner benzene ring like structure, monocyclic. (molecular formula is **(N_2C_4)**. Three major types of bases are derived from the parent pyrimidine bases i.e. thymine, cytosine and uracil.

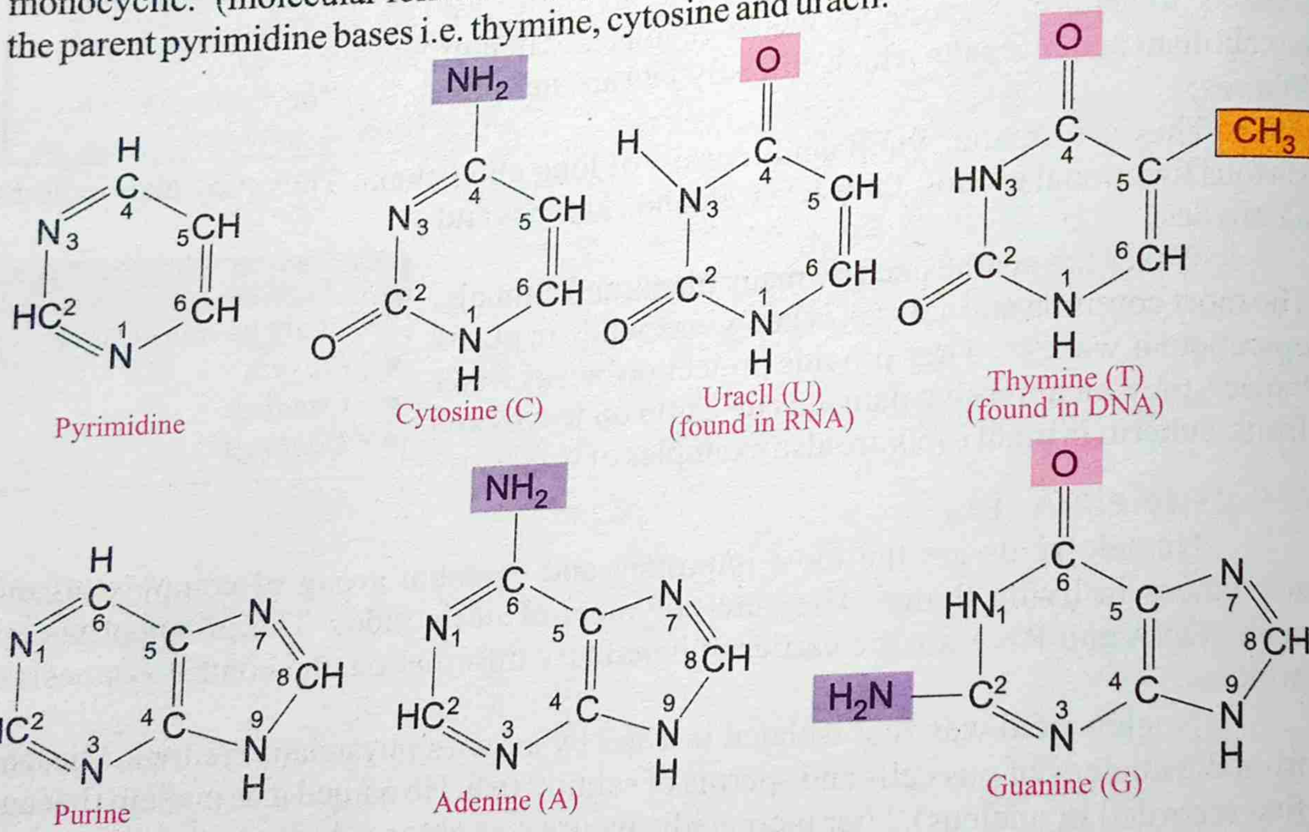


Fig. 2.17 Types of Nitrogenous Bases

Purine bases: These are second type of nitrogen containing heterocyclic organic molecules consist of two cycles. It is nine member bicyclic molecule **(N_4C_5)**. They are of

two types, i.e., adenine and guanine.

Pentose sugars:

There are two types of 5 carbon containing pentose sugars which are yielded during complete hydrolysis of nucleic acids i.e. deoxyribose **($C_5H_{10}O_4$)** from DNA and ribose **($C_5H_{10}O_5$)** from RNA.

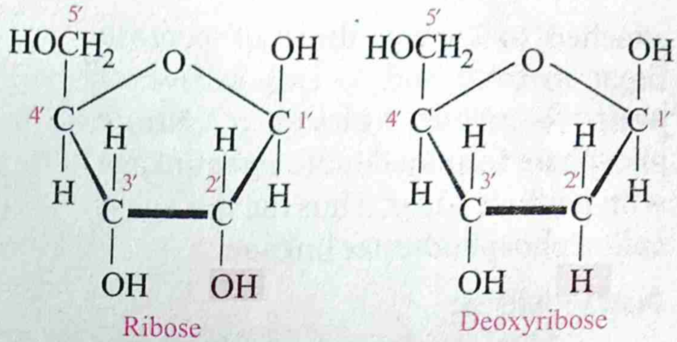


Fig. 2.18

Deoxyribose has almost the same structure like ribose, the only difference is having one atom of oxygen less at carbon no. 2.

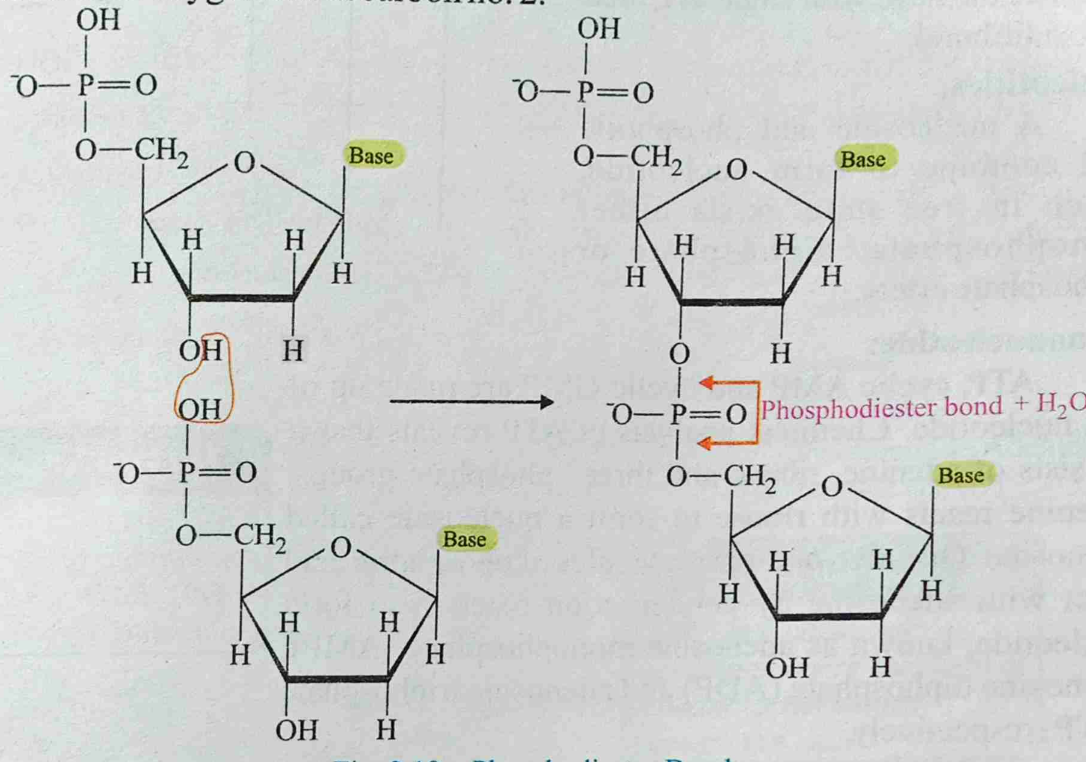


Fig. 2.19 Phosphodiester Bond

Phosphoric Acid:

Phosphoric Acid **(H_3PO_4)** has the ability to develop ester linkage with hydroxyl group (OH) of pentose sugar.

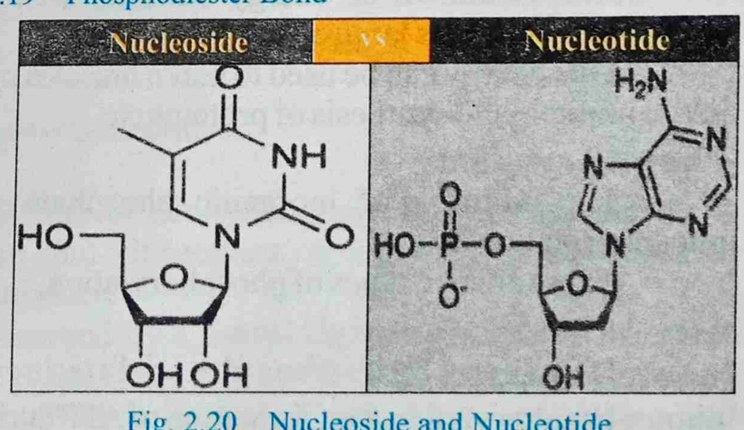


Fig. 2.20 Nucleoside and Nucleotide

Phosphodiester linkage:

In a typical nucleotide the nitrogenous base is always attached to carbon one of pentose sugar while phosphoric acid (in a chain) is

attached to carbon three of pentose sugar in front and to carbon five of pentose sugar behind it. Since phosphate forms a double ester linkage with pentose sugar. Thus the linkage is called phosphodiester linkage.

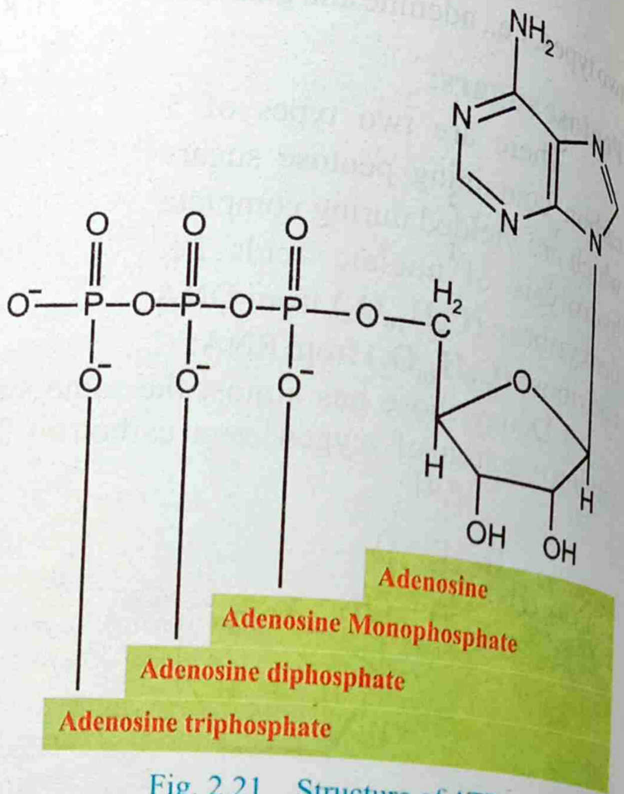


Fig. 2.21 Structure of ATP

Nucleosides:

Nucleoside is formed when a nitrogen containing base is linked with a pentose sugar. The bond that combines the base with sugar is called glucosidic bond.

Nucleotides:

A nucleoside and phosphoric acid combine to form nucleotide, which in free state exists either monophosphate, diphosphate or triphosphate esters.

Mononucleotide:

ATP, cyclic AMP and cyclic GMP are made up of one nucleotide. Chemical analysis of ATP reveals that it consists of adenine, ribose and three phosphate groups. Adenine reacts with ribose to form a nucleoside called adenosine. One, two or three molecules of phosphoric acid react with adenosine by condensation reaction to form nucleotide, known as adenosine monophosphate (AMP), adenosine diphosphate (ADP) and adenosine triphosphate (ATP) respectively.

> **Do you know?**
> *Nucleotides are also component of ATP, cAMP, NAD, FAD and certain coenzymes.*

ATP is known as energy currency of the cell, being organic phosphates on hydrolysis it releases large quantity of energy.

This energy can be used to make muscles contract, drive active transport, transmit nerve impulse and synthesis of proteins etc.

Phosphorylation:

The addition of inorganic phosphate with an organic molecule is called phosphorylation.

There are two types of phosphorylation.

1. **Photophosphorylation**

If energy for phosphosrylation comes from sunlight is called photophosphorylation e.g., formation of ATP during photosynthesis.

2. Oxidative phosphorylation

If energy for phosphorylation comes from breakdown of organic molecule in cell is called as oxidative phosphorylation. e.g., formation of ATP during cellular respiration.

Dinucleotide (Nicotinamide adenine dinucleotide NAD)

Most enzymes need additional chemical components to become functional called cofactors. Cofactors may be inorganic or organic but other than proteins are known as coenzymes e.g., nicotinamide adenine dinucleotide (NAD) and many vitamins.

Structure of NAD:

NAD consists of two nucleotides, one consists of nicotinamide base, sugar and phosphate group, Other consists of adenine base, sugar and phosphate group. Both nucleotides are linked by their phosphate group forming a dinucleotide. NAD is derived from nicotinic acid or niacin (vitamin B). In metabolism, NAD is involved in redox reactions, carrying electron from one reaction to other. This co-enzyme is, therefore, found in two forms in cells. NAD^+ is an oxidizing agent. It accepts two energetic electrons and a proton from other molecules and become reduced (NADH), which can be used as reducing agent to donate electorns. These electron transfer reactions are the main function of NAD.

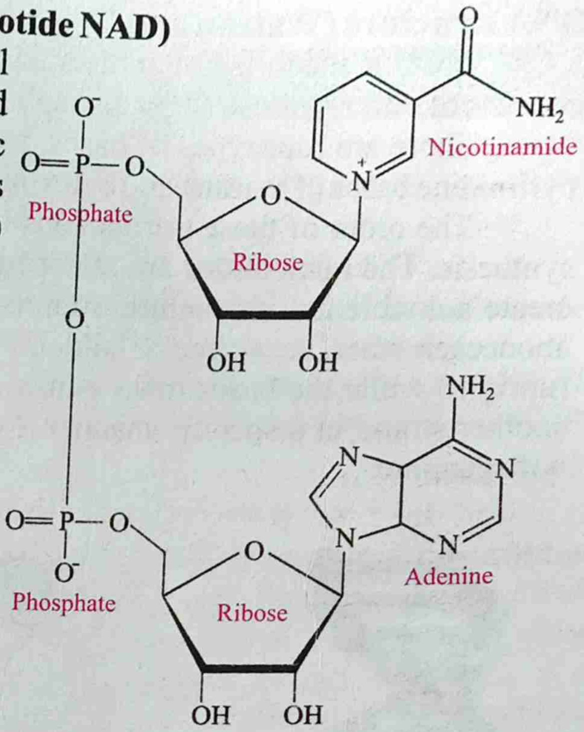


Fig. 2.22 Nicotinamide Adenine Dinucleotide (NAD)

> **Do you know?**
> *cAMP, is a chemical messenger, carry message of proteinous hormones through the cell.*

Another example of dinucleotide is flavin adenine dinucleotide (FAD) which is also a co-enzyme sometime used instead of NAD. It accepts two electrons (reduced) and two protons to become $FADH_2$.

Polynucleotides:

DNA and RNA are examples of polynucleotides.

Deoxyribonucleic acid (DNA):

Deoxyribonucleic acid is a polymer of deoxyribonucleotides found mostly in nucleus, few traces in mitochondrion and chloroplast. It contains instructions, an organism needs to develop, live and reproduce.

Discovery: Nucleic acid was first observed by a Swiss biochemist named Friedrich Meischer in 1869. But for long time researchers did not find its exact structure and function. It was until 1953 that James Watson, Francis Crick, Maurice Wilkins and

Rosalind Franklin figured out the structure of DNA (double helix).

Watson, Crick and Wilkins were awarded nobel prize of medicine in 1962 for giving comprehensive information for the structure and importance of DNA.

DNA structure (Watson and Crick Model of DNA):

DNA is made up of molecules called deoxyribonucleotides. Each nucleotide consists of a deoxyribose sugar, phosphate group and a nitrogen containing base.

There are four types of bases, two purine bases (Adenine and guanine) and two pyrimidine bases (Thymine and cytosine).

The order of these nitrogenous bases determines DNA's instructions for protein synthesis. The nucleotides are attached together to form two long strands that twist to create a double helix structure, running in opposite direction antiparallel and winding about each other like a circular ladder. The phosphate and sugar molecules make the sides (upright) while the bases make rungs. The bases on one strand pair with the bases on another strand in a specific manner. Adenine always pairs with thymine and cytosine with guanine.

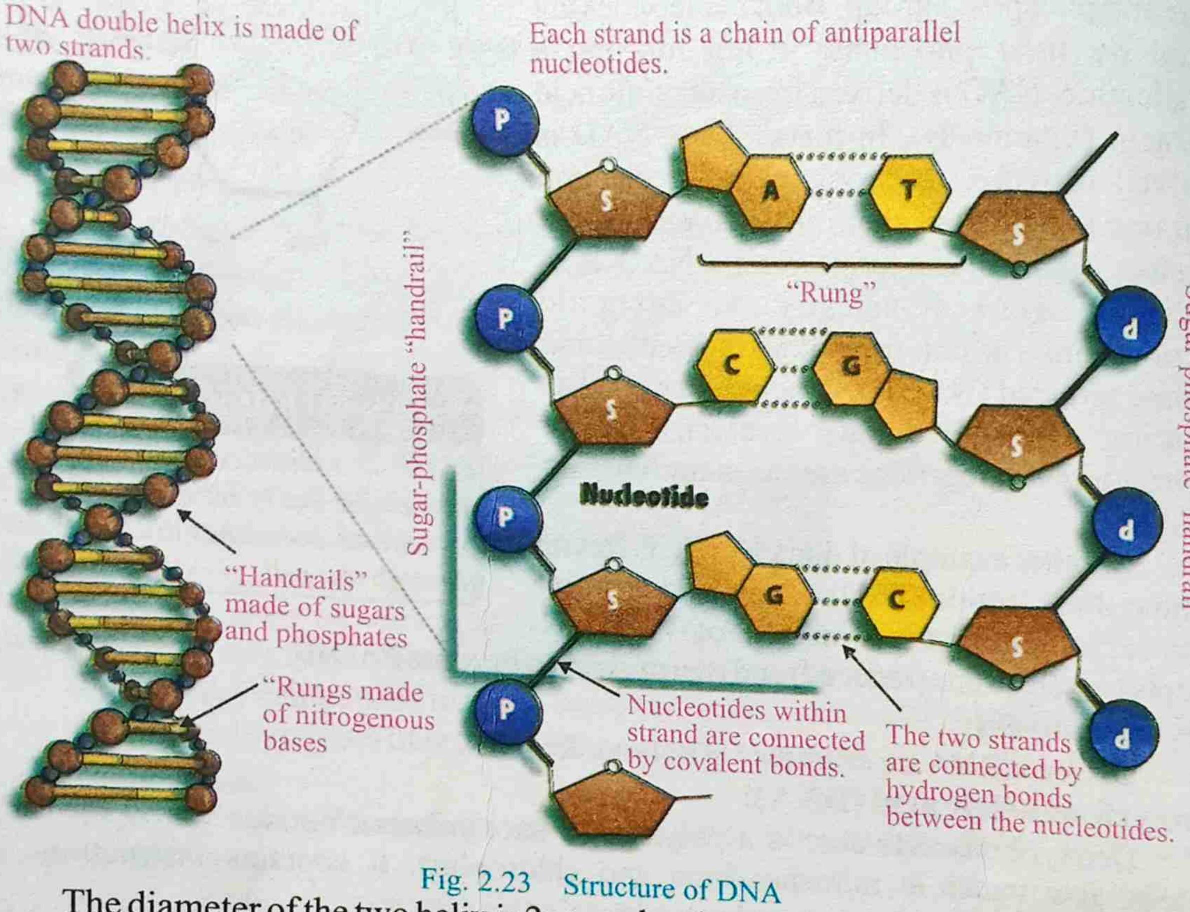


Fig. 2.23 Structure of DNA

The diameter of the two helix is 2nm and makes a full spiral turn at every 3.4nm.

The amount of DNA is fixed for a particular species as it depends upon the number of chromosomes. The amount of DNA in germ cells (sperm and egg) is half to that of somatic cells.

Structure of Ribonucleic Acid (RNA):

RNA is a long unbranched polymeric molecule formed by interlinkage of four monomeric units known as ribonucleotides of adenine, guanine, cytosine and uracil bases.

RNA molecules are single stranded, except Reo virus. However, some RNA molecules have regions in which hydrogen bonds between A = U and G ≡ C bases are formed between different regions of the same molecule thus coiled itself look like double stranded hair-pin loops. RNA is mostly present in cytoplasm but synthesized within the nucleus by using only one strand of DNA as template (3'—5') direction. Thus it is true copy of the genetic information contained in DNA. RNA helps DNA in protein synthesis. In some animal and all plant viruses, RNA functions as hereditary material. The amount of RNA varies from cell to cell.

Do you know?

About 97% of transcriptional output is non protein coding in eukaryotes. So they are called non coding RNA (ncRNA).

What is a Gene?

A gene is a region of DNA which is made up of specific sequence of nucleotides, which codes a specific polypeptide chain. A nucleotide sequence of gene in DNA specifies, the amino acid sequence of proteins through the genetic code. A set of three nucleotides known as codon each correspond to a specific amino acid e.g., if a polypeptide chain has 100 amino acids then the number of nucleotide in a gene will be 300.

Types of RNA:

There are three main types of RNA which are synthesized from different parts of DNA in a process called transcription and then are moved out in the cytoplasm to perform specific functions.

Main three types are mRNA, tRNA and rRNA.

Messenger RNA:

The mRNA is a type of RNA that carries information from DNA to the ribosomes, the site of protein synthesis in a cell. The coding sequence of mRNA determines the amino acid sequence in protein that is to be produced. There are many types of mRNA because for the translation of every polypeptide chain a specific mRNA is required. (mRNA is about 3—5% of total RNA of cell).

Transfer RNA:

The tRNA is a small RNA chain of about 80 nucleotides that transfers a specific amino acid to the growing polypeptide chain at ribosomal site of protein synthesis. There are at least 20 types of tRNA in each cell because for each amino acid a separate transfer RNA is required. About 60 types of tRNA have been identified so far. Transfer RNA are about 15% of total RNA of cell.

Ribosomal RNA:

The rRNA is the catalytic component of ribosome. It is synthesized by the genes present on DNA of several chromosomes found within the region of nucleus called nuclear organizer. The base sequence of rRNA of all organisms is similar thus there is only one type of rRNA. It is most abundant about 80% of total RNAs of the cell.

2.7 Conjugated Molecules

Conjugated molecules are types of molecules that are formed by the combination of two different classes of molecules e.g., when carbohydrate molecule combines covalently with protein, a more complex molecule is formed called glycoprotein. Some other examples of conjugated molecules are as under.

Lipoproteins: The lipoprotein forms when lipid combines with protein. These types of molecules are frequently found in cell membranes and other types of membranes in the cell like mitochondria, endoplasmic reticulum, nuclear membrane etc.

Nucleoproteins: It is formed by the combination of nucleic acid with protein e.g., Ribosome and chromosomes of eukaryotes are basically nucleoproteins in composition.

Glycolipids: These are lipids with a carbohydrate attached with glucosidic bond. Such molecules are part of cell membrane .

Table 2.3 Differences between DNA and RNA.

DNA	RNA
1. It is mainly located in the nucleus. A small quantity occurs in mitochondria and chloroplast.	1. It is mainly located in the cytoplasm. A small quantity is found in the nucleus.
2. Its quantity is constant in each cell of a species.	2. Its quantity varies in different cells.
3. It contains deoxyribose sugar. Bases are A, G, C and T.	3. It contains ribose sugar. Bases are A, G, C and U.
4. It consists of 2 polynucleotide chains held together by hydrogen bonds, and coiled into a double helix.	4. It consists of a single polynucleotide chain. It may fold on itself due to hydrogen bonds and coiled into a pseudohelix.
5. It is of 2 types: linear intranuclear and circular extranuclear.(such as in bacteria).	5. It is of 3 types: mRNA, tRNA, rRNA. Each type has many subtypes.
6. It is the genetic material in all organisms.	6. It is the genetic material only in certain viruses.
7. It transfers its information to mRNA (Transcription).	7. mRNA transfers its information to polypeptide (Translation).

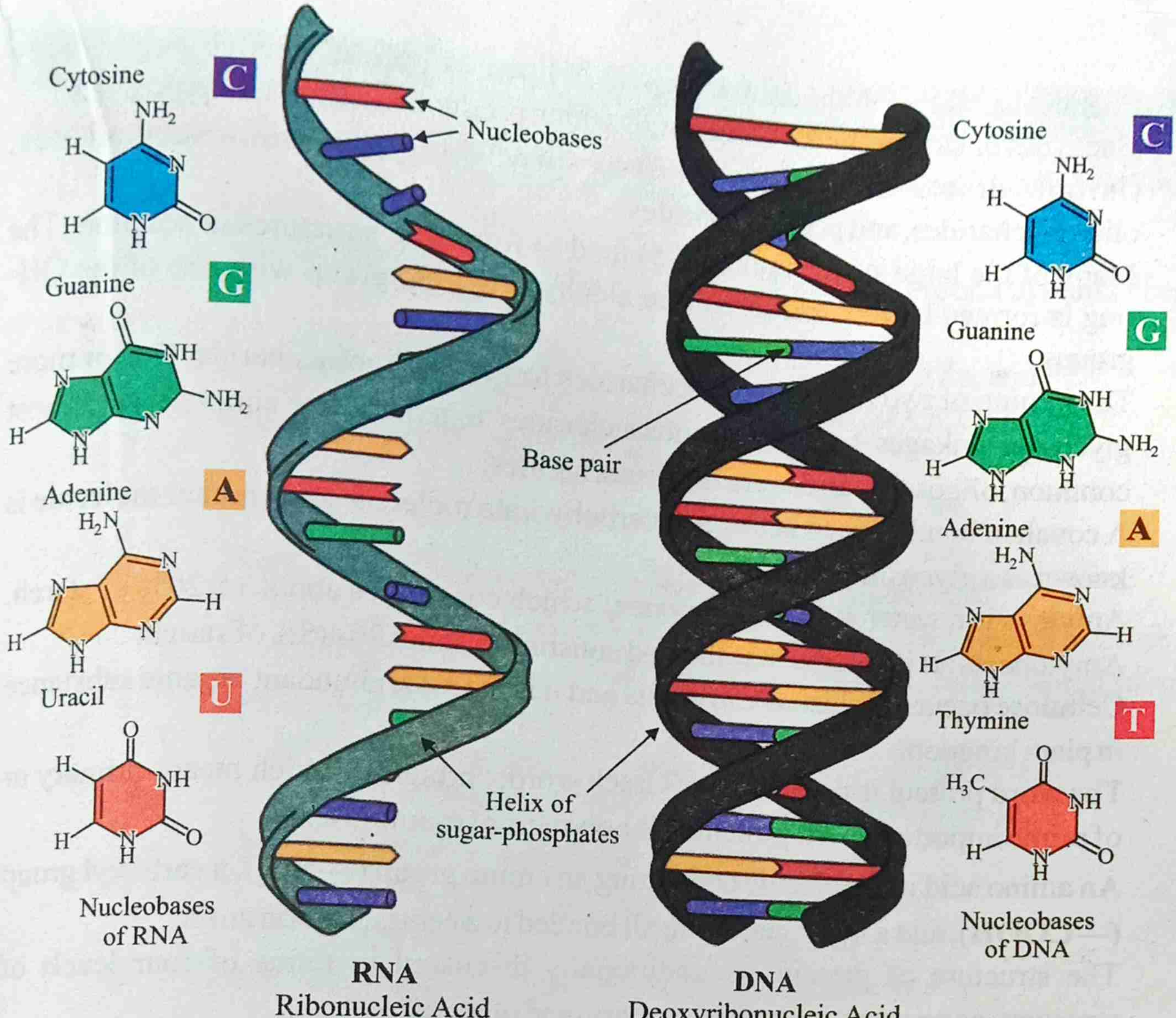


Fig. 2.24 Difference between DNA and RNA

Critical Thinking

Why reducing sugar gets red when tested with Benedict`s solution? The Benedict`s solution contains copper II salt (blue) that can be converted to copper I oxide (red). We say it has been reduced. Some sugars are able to cause this change, and thus called reducing sugars. Benedict`s test can, therefore, be used to test for the presence of reducing sugars such as glucose, fructose and maltose.

SUMMARY

- Hydrogen, oxygen, carbon, and nitrogen constitute more than 97% of the atoms in the human body.
- Water is an important compound for the life and its proper functioning is due to its polarity, low density in ice form, high heat of vaporization, high heat capacity, cohesive and adhesive properties.

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

Choose the best correct answer.

A.

1. The six elements that make up 99% of all elements found in human beings are
   (a) C, H, O Na, Mg and P (b) C, N, O, S Zn, and P
   (c) H, O, C, Ca, P and N (d) C, H, O, Ca, Cu and S.
2. What are the most diverse molecules in the cell?
   (a) Lipids (b) Mineral salts
   (c) Proteins (d) Carbohydrates.
3. One of the following groups contains all polysaccharides?
   (a) Sucrose, glucose and fructose (b) Maltose, lactose and fructose
   (c) Glycogen, sucrose and maltose (d) Glycogen, cellulose and starch
4. Lactose is composed of
   (a) Glucose + galactose (b) Fructose + galactose
   (c) Glucose + fructose (d) Glucose + glucose.
5. An ATP molecule is consisting of
   (a) Mono nucleotide (b) Nucleoside
   (c) Polynucleotide (d) Vitamin
6. Lipids are insoluble in water because lipid molecules are
   (a) Hydrophilic (b) Hydrophobic
   (c) Neutral (d) Polar
7. In double helix of DNA, the two DNA strands are
   (a) Coiled around a common axis (b) Coiled around each other
   (c) Coiled differently (d) coiled over protein sheath.
8. In DNA the nitrogenous base that takes place of uracil is:
   (a) Thymine (b) Adenine
   (c) Guanine (d) Cytosine
9. Proteins are synthesized from
   (a) Glucose (b) Fatty acids
   (c) Amino acids (d) A-ketoglutaric acid.

B. **Fill in the Blanks.**

1. The branch of biology which deals with the chemical compounds and chemical processes is called ______.

Introduction

There are thousands of chemical reactions taking place in the body of a living organism. The sum of all these chemical reactions is called metabolism. These reactions must take place with a high speed to sustain life. A special group of chemicals responsible for facilitating and speeding up these reactions are called enzymes. Enzymes are mostly protein in nature and coded by genes. They are large group of chemicals which catalyze almost all metabolic reactions in the cell and other parts of the organisms e.g., in digestive tract.

The term enzyme was coined from a Greek word "levened" or "in yeast". First enzyme was discovered by **Payen and Persoz** from germinating barley seeds in 1833 and named it **diastase**. The term enzyme was introduced by **Wilhelm kuhne in 1877**.

Enzymes can be defined as " the **thermolabile biocatalyst**" protein in nature, specific in function and coded by DNA.

They work inside or outside of the cell. The substance on which enzyme acts is called **substrate** which is usually very smaller than enzyme. When enzyme combines with substrate it forms an enzyme-substrate complex. After enzyme substrate reaction product is formed and enzyme itself remains unchanged which can be used again for another substrate. Most enzymes are protein in nature, although a few are catalytic RNA molecules called **ribozymes**, that can catalyze specific substarte in a similar way as proteinaceous enzymes.

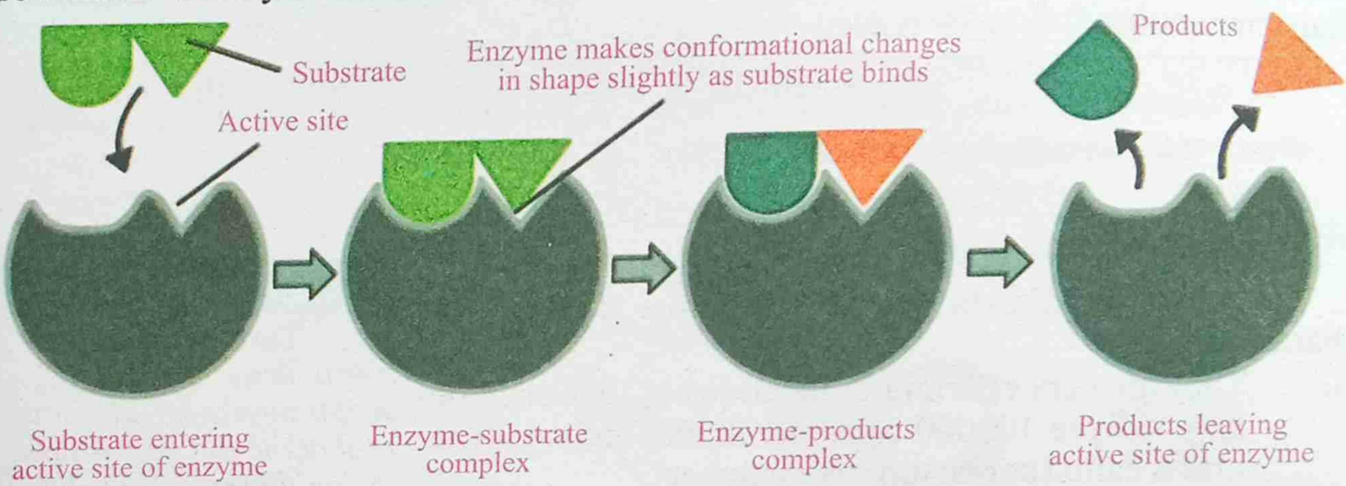


Fig.3.1 Mechanism of Enzyme Action

3.1 Structure of Enzymes

Enzymes are generally globular proteins. The sequence of amino acids specifies the structure of active site which determines the catalytic activity of enzyme. An enzyme may have one or more active sites. Active site of enzyme consists of two parts i.e.,

Do you know?

Ribozyme is found in ribosomes. It controls polypeptide elongation during protein synthesis such as peptidyl transferase.

a. **Binding site** where substrate attaches.

b. **Catalytic site** where catalysis of substrate takes place.

The catalytic site is very small portion comprises of (2 to 12) amino acids.

Chemical Nature of Enzymes:

Most enzymes are proteins, so each has its own specific structure, which is required for its proper functioning. A complete functional enzyme is called holoenzyme.

The **holoenzyme** consists of two parts

a. **Apoenzyme:** It is the proteinaceous part of an enzyme.

b. **Cofactor:** It is non-proteinaceous part of an enzyme.

Apoenzyme + Cofactor = Holoenzyme.

Some enzymes are only composed of protein i.e., no cofactors are attached with them e.g. lipase.

Physical Nature of Enzymes:

Enzymes have relatively high molecular weight e.g., the molecular weight of **peroxidase** is 40,000 Daltons or 40 KDa and **catalase** 250 KDa approximately. Enzymes due to proteinaceous nature may denature in high temperature. The enzymes form colloidal suspension in the cytosol, therefore, at low temperature their activity may decrease or stop. High fever is harmful for the body because enzymes may denature in high temperature.

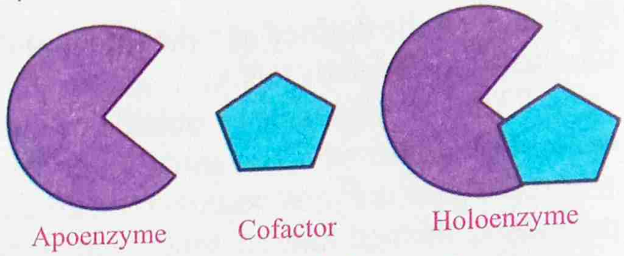


Fig.3.2 Holoenzyme

Activity

If an enzyme breaks three lac moles of substrate in a second. What will be its turnover numbers?

Catalytic Characteristics of Enzymes:

Being catalysts, enzymes show following characteristics.

i) They are very **efficient** in function e.g., one enzyme may catlyze 100000 substrate in one second. (The unit is called as one turnover number).

ii) Enzymes need **specific temperature** for their proper functioning. So drinking cold water during meal is medically wrong.

iii) Enzymes need **specific pH** for their proper functioning.

iv) Enzymes are highly **specific** i.e., one enzyme acts only a specific substrate e.g., amylase acts only on amylose.

v) Enzymes remain constant after the reaction so they can be used again and again.

vi) Enzyme may be studied in living cell ***(in vivo)*** or outside living cell i.e., in glassware ***(in vitro)***.

vii) Most of enzymes need **co-factor** for their functioning.

viii) Enzymes need **aqueous environment** for their functioning, that`s why we feel thirst after taking meal.

Tit bits

Turn over unit

If you turn something over, or if it turn over, it is moved so that the top part is now facing downward or change or reversal of position.

Tit bits

Dalton

A very small unified atomic mass unit (symbol Da) in biology, one hydrogen atom has mass of one Da. The molecular weight of proteins and other macromolecules are usually measured in kilodaltons (KDa).

Three dimensional structure of enzyme:

The enzymes are globular proteins. The specificity of enzymes comes from their unique three dimensional structure. Tertiary structure of a protein or any other macromolecule, play important role in their proper functioning.

The simple protein consists of only one long polypeptide chain e.g., ribonuclease consists of 124 amino acids. The kind of amino acids and the sequence in which they are

arranged determines the three dimensional structure of an enzyme.

Enzyme Cofactors:

Some enzymes do not need additional components to show full activity. However, most of the enzymes require non-protein molecule called cofactors to be bound for activity. Cofactor can be either inorganic metal ions or organic compounds like flavin or haeme. These cofactors serve many purposes e.g., **metal ions** help in making enzyme-substrate complex either by moulding active site or shape of substrate. The **organic substances** may be **co-enzyme** which are released from the enzyme active site during the reaction. They are loosely attached with enzyme. **Prosthetic groups** are tightly bound with enzyme hence the permanent part of enzyme. Most vitamins are co-enzymes or components of co-enzymes. That is why vitamins are needed in our daily life.

3.2 Mechanism of Enzyme Action

Enzymes must bind their substrate before they can catalyze any chemical reaction.

To understand the mechanism of enzyme action two models have been proposed.

Lock and Key Model:

This model was developed by a Germen chemist **Emil Fischer** in 1894.

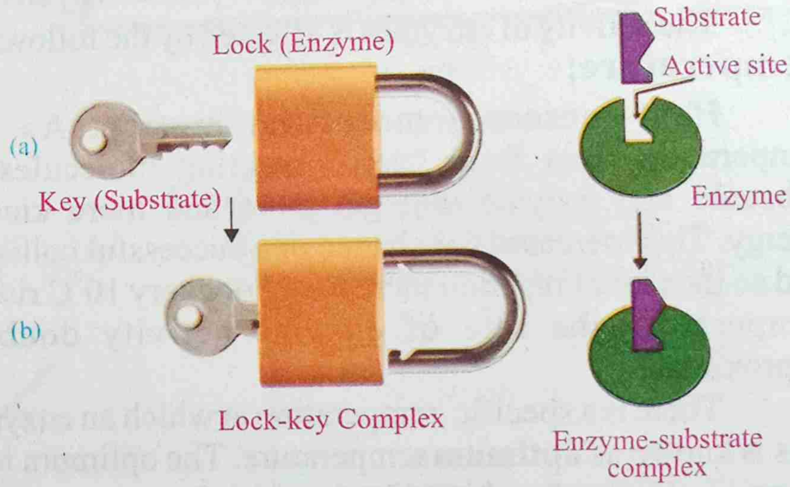


Fig.3.3 Emil Fischer Model

The specific action of enzyme with a single substrate can be explained using a lock and key analogy. In this analogy the lock is the enzyme and the key is the substrate. Only the correctly sized key that is substrate fits into the key hole which is active site of lock that is enzyme. The same enzyme can be used to catalyze hundreds of same substrates. The enzymes work on this mechanism are called non regulatory enzymes e.g., lipase, amylase etc. This model explains the specificity of enzymes but does not say anything about the change in active site.

Activity

Study the lock and key enzyme action and induced fit model of enzyme action by animated videos through internet.

Induced-Fit Hypothesis (Model):

In 1958 **Daniel Koshland** suggested a modification to the lock and key model. According to induced-fit model the active site of enzyme is a flexible structure. Enzyme

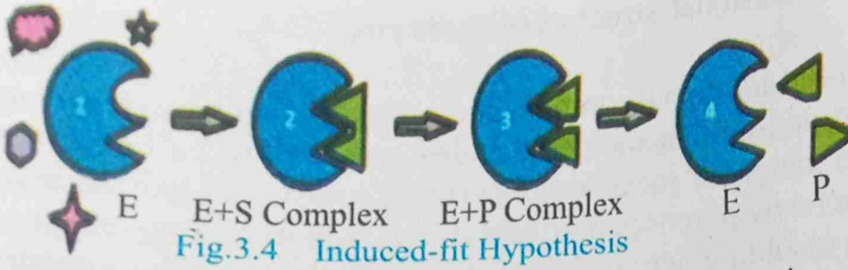


Fig.3.4 Induced-fit Hypothesis

> **Tit bits**
> *Luciferase is an enzyme in fireflies responsible for light production.*

molecules are in an inactive form. To become active, enzymes must undergo slight conformational changes in the structure to accommodate the substrate. A suitable analogy would be that of hand and gloves. The hand corresponds to the substrate and glove as enzyme is shaped by insertion of the hand. Enzymes which follow the induced-fit mechanism are called regulatory or allosteric enzymes e.g hexokinase.

> **Tit bits**
> *Enzymes are denatured by heat but not by cold thus enzymes stored in below 0°C are able to function after thawing.*

3.3 Factors Affecting The Rate of Enzyme Action

The activity of enzymes is affected by the following factors.

Temperature:

Heat increases molecular motion. As the temperature rises from "zero" reacting molecules of substrate and enzyme will get more and more kinetic energy. This increases the chance of a successful collision and so the rate of reaction increases. For every 10°C rise in temperature the rate of enzyme activity doubles approximately.

> **Do you know?**
> *The food like meat, fruits may turn bad because of the enzyme activity. Therefore, it is advised to keep such food in refrigerator.*

There is a specific temperature at which an enzyme catalytic activity is fastest and this is known as **optimum** temperature. The optimum temperature for enzymes found in human is 37°C. After this point the rate of enzyme activity will decrease and at 45-50°C

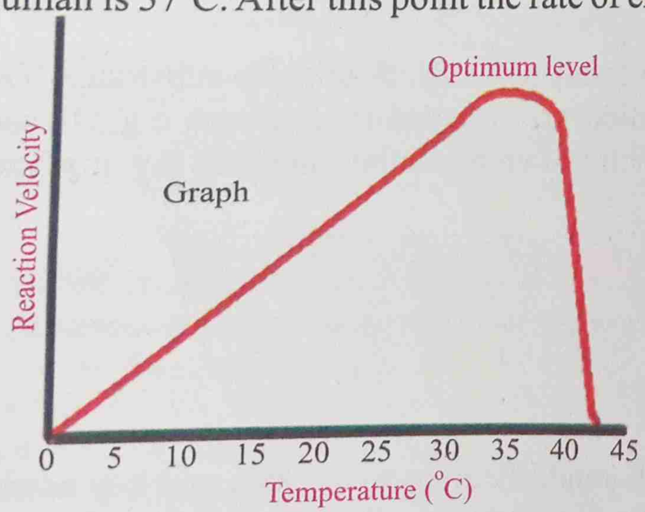


Fig.3.5 Effect of Temperature on enzyme action

Table 3.1 Optimum pH of different enzymes

Enzymes	*Optimum pH*
Pancreatic Lipase	*7.4-7.8*
Pepsin	*2.0*
Trypsin	*7.8 - 8.7*
Maltase	*6.1 - 6.8*
Arginase	*9.7*
Sucrase	*4.5*

the enzyme activity will be stopped, as enzyme binding site will denature at this temperature. Some bacteria live in hot springs so optimum temperature for their enzymes is more than 37°C. Such enzymes have been used in biological washing powders and detergents. That is why cloth washing need lukewarm water, not too hot.

pH:

Every enzyme needs a specific pH for its proper functioning. The pH at which an enzyme works maximum is called its optimum pH. Some enzymes work best in acidic medium e.g., pepsin, some in neutral medium e.g., amylase and other in alkaline medium e.g., lipase.

However, most of enzymes in our body work in the range of pH 6-8. Some enzymes may work on both acidic and alkaline media e.g., papain enzyme in green papaya.

Change in pH alters the ionic charge of acidic and basidic groups as a result ionic bonding is disrupted. This ionic bonding is needed to maintain the specific shape of enzyme. Thus the change in pH may change the shape of enzyme as well as denature active site.

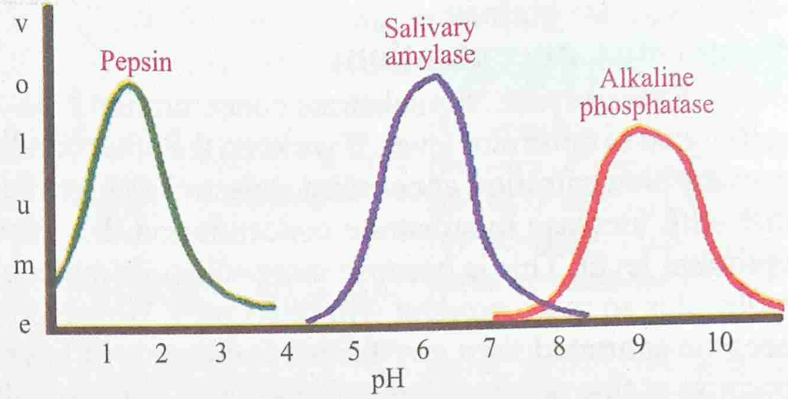


Fig.3.6 Effect of pH on enzyme action

Activity

Find the pH of different food substances by searching internet.

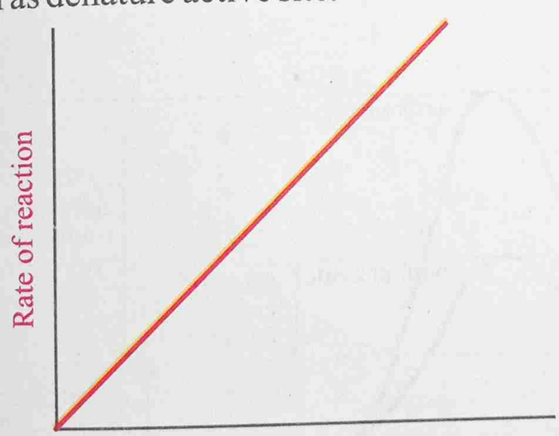


Fig. 3.7 Enzyme Concentration

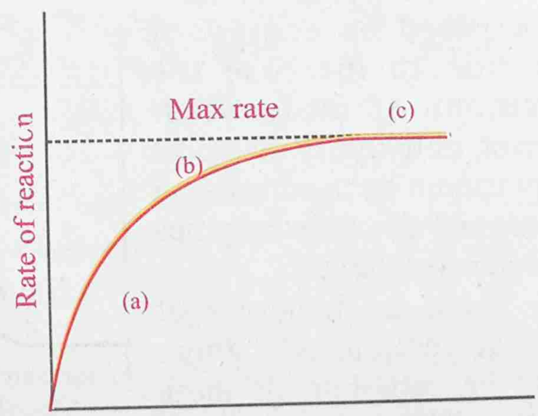


Fig. 3.8 Concentration of Substrate

Tit bits

A restriction enzyme is an enzyme that cleaves DNA into fragments. These enzymes are found in bacteria and provide a defense mechanism against invading viruses. They restrict the entry of foreign DNA in to the host.

Enzyme Concentration:

Enzyme concentration is directly proportional to enzyme activity. If substrate concentration is maintained at high level , and other conditions such as pH and temperature is kept constant then with the increase of enzyme concentration the activity of enzyme will also increase and with the decrease of enzyme concentration the activity of enzyme will also decrease.

Usually in natural conditions the substrate concentration is always high than enzymes. However, when the enzyme concentration become saturated as compared to substrate, then the rate of reaction will not increase further, this maximum rate (Vmax value) is never obtained.

Substrate Concentration:

Like enzymes the substrate concentration is also directly proportional to enzyme activity up to optimum level. If we keep the other conditions such as temperature, pH and enzyme concentration at constant state and change the amount of substrate then we find that with increase in substrate concentration the reaction rate will increase only up to optimum level. This is because more substrate molecules will be colliding with enzyme molecules so more product will be formed. However, at certain concentration substrate become saturated then any further increase will have no effect on the rate of reaction because at this point all the active sites of enzyme will be occupied, maximum rate (V-max).

Energy of Activation(EA):

The minimal amount of energy required to start a chemical reaction is called activation energy. It is denoted by EA and measured in units of kilo joules per mole (KJ/Mol) or kilocalories per mole (Kcal/Mol).

In non-living system, heat is used as energy of activation to increase the movement of molecules. However, in living system heat energy cannot be used because this heat may denature enzymes and proteins of the cell.

There are hundreds of reactions continuously going on in the cell. For all these reactions large amount of activation energy is required. Such a huge amount of energy is not present in living organisms. However, living organisms possess enzymes which lower the activation energy. In the

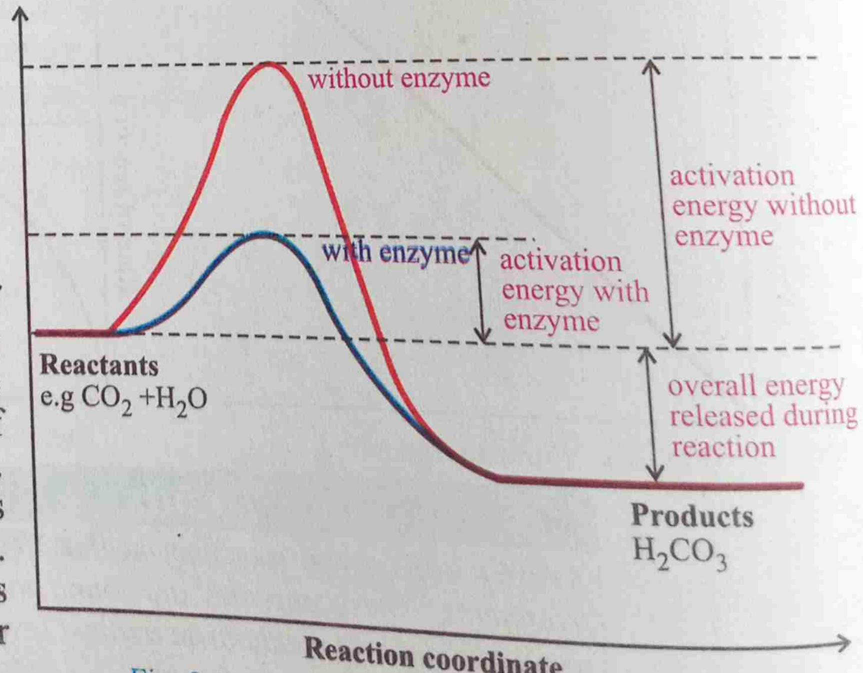


Fig. 3.9 Effect of enzyme on activation energy

presence of enzymes less activation energy is required but in the absence of enzymes more activation energy is required to convert a substrate into product.

3.4 Enzyme Inhibition

The term enzyme inhibition means to stop enzyme from its expression (functioning), usually by enzyme inhibitors or due to change in temperature or pH. Such molecules or substances which stop enzyme activity are called enzyme inhibitors, such as drugs, toxins, products of enzymes etc. Some of the poisons are enzyme inhibitors, that`s why a person exposed to poison may die. On the other hand, there are enzyme activators which bind to enzyme to increase enzyme activity.

Tit bits

Cyanides are powerful poisons of organisms because they can kill them by inhibiting cytochrome oxidase essential for respiration.

Types of Inhibitors:

Generally there are two main types of enzyme inhibitors that is irreversible and reversible inhibitors.

Irreversible Inhibitors:

These inhibitors stop enzyme activity permanently either by destroying (denaturing) the active site of enzyme or occupying active site by making covalent bond with active site. The irreversible inhibitors often contain reactive functional groups e.g., aldehydes, alkenes. These electrophilic groups make covalent bonds with amino acid side chains.

Scientific Knowledge

The enzymes which catalyze chemical reaction again and again are called regulatory enzymes.

The irreversible inhibitors may be natural or artificial e.g., poisons, venom of snakes, drugs etc.

Reversible Inhibitors:

Such inhibitors which attach to enzymes with non-covalent interactions such as hydrogen bond, hydrophobic interactions and ionic bond. These inhibitors generally do not undergo chemical reactions when bonded to enzyme and easily removed from enzymes.

Reversible inhibitors are of two types.

Competitive Inhibitors:

Such inhibitors which have similar shape to the substrate molecule hence compete with substrate to occupy active site. The

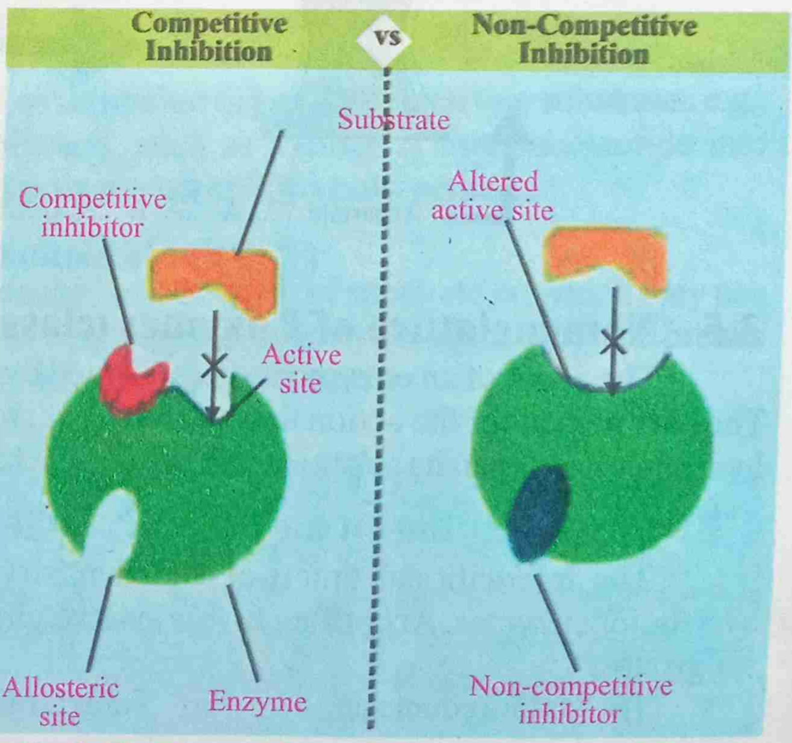


Fig. 3.10 Competitive and Non-competitive inhibitors

process of inhibition depends on the concentration of substrate and inhibitors. With high concentration of inhibitors the chances of inhibition are also high.

Non Competitive Inhibitors:

These inhibitors do not possess structural similarities with the substrate molecule, therefore, attach to allosteric site of enzyme than active site. The attachment of inhibitors changes the shape of active site. Thus substrate cannot bind with active site. Such type of inhibitors are not affected by substrate concentration.

Feed Back Inhibitons:

The production of enzymes, hormones and other products should be in limits to maintain homeostatic conditions. The over production of any product in the body, may prove fatal.

The mechanism through which the production of different products controlled in the body is known as feedback mechanism.

Many enzyme catalyzed reactions are carried out through the biochemical pathways. In these pathways the product of first reaction becomes the substrate for the next reaction. At the end of the pathway a desired product is synthesized. In order to regulate the concentration of that product the biochemical pathway needs to be shut down. This is done through feedback mechanism (automatic system) e.g., the amino acid aspartate changes into threonine through a sequence of five enzymatic reactions. When threonine production become sufficient, it starts accumulating on the allosteric site of enzyme. Thus changes the shape of active site as a result threonine production stops.

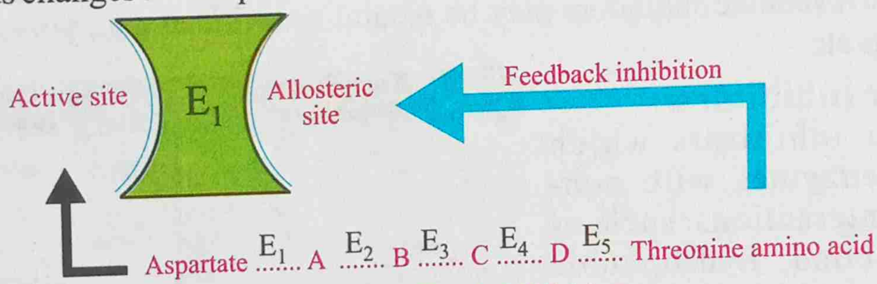


Fig. 3.11 Feedback Inhibition

3.5 Nomenclature of Enzymes (classification of enzymes)

The name of an enzyme is often formed by adding "ase" to the name of substrate. They are named for the action they perform e.g., hydrogenase is an enzyme that removes hydrogen atom from its substrate and cellulase which breaks down cellulose.

1. Classification on the basis of reaction types or functions

The international union of Biochemistry in 1961 has given a nomenclature system for enzymes. According to this system the enzymes are classified into following six groups.

i) Oxidoreductases	ii) Transferases	iii) Hydrolases
iv) Lyases	v) Isomerases	vi) Ligases

Oxidoreductases:

These enzymes catalyse different types of oxidation-reduction reactions i.e. removing or adding electrons or hydrogen ions from or to the substrate. The sub classes of these enzymes are oxidases, oxygenases and peroxidases.

Transferases:

These enzymes cause transfer of group from one molecule to another molecule called transferases. Examples of such groups are amino group, carboxyl group, methyl and carbonyl group. Example of transferases enzymes are hexokinases which transfer phosphate group from ATP to glucose.

Hydrolases:

These enzymes break down proteins, fats and carbohydrates by adding water so are called hydrolases e.g., lipase, sucrase, maltase, cellulase, proteinase etc.

Lyases:

These enzymes catalyse the breakdown of specific covalent bond and removal of functional group without hydrolysis e.g., decarboxylase, add or remove carboxyl group, deaminases, add or remove amino group etc.

Isomerases:

Isomers are molecules having similar molecular formula but different structural formula e.g., glucose, fructose and galactose are isomers having same molecular formula $C_6H_{12}O_6$ but have different structures. Isomerase enzymes bring about intramolecular rearrangement within a molecule e.g., phospho-hexose isomerase change glucose 6-phosphate to fructose 6-phosphate.

Ligases:

These enzymes are responsible for formation of bond between two substrates e.g., polymerase joins monomers into polymers, such as joining of mononucleotide into dinucleotide or polynucleotide by DNA polymerase or RNA polymerase.

2. Classification on the basis of name of substrate

Enzymes can also be classified on the basis of name of substrate on which they use e.g., protease breaks protein into amino acids, lipase hydrolyses lipid, amylase breaks down amylose, nuclease acts on nucleic acid, diastase acts on starch etc.

Table 3.2 Comparison between reversible and irreversible enzyme inhibition

Reversible inhibitor	Irreversible inhibitor
1- Binds via non covalent interactions. 2- Do not perform any chemical changes. 3- Can be reversed, as there is no bonding between the inhibitor and substrate.	1- Binds via covalent interactions. 2- Inhibitor binds to the substrate and prevents catalytic activity of enzymes. 3- Irreversibility is due to strong covalent bonding.

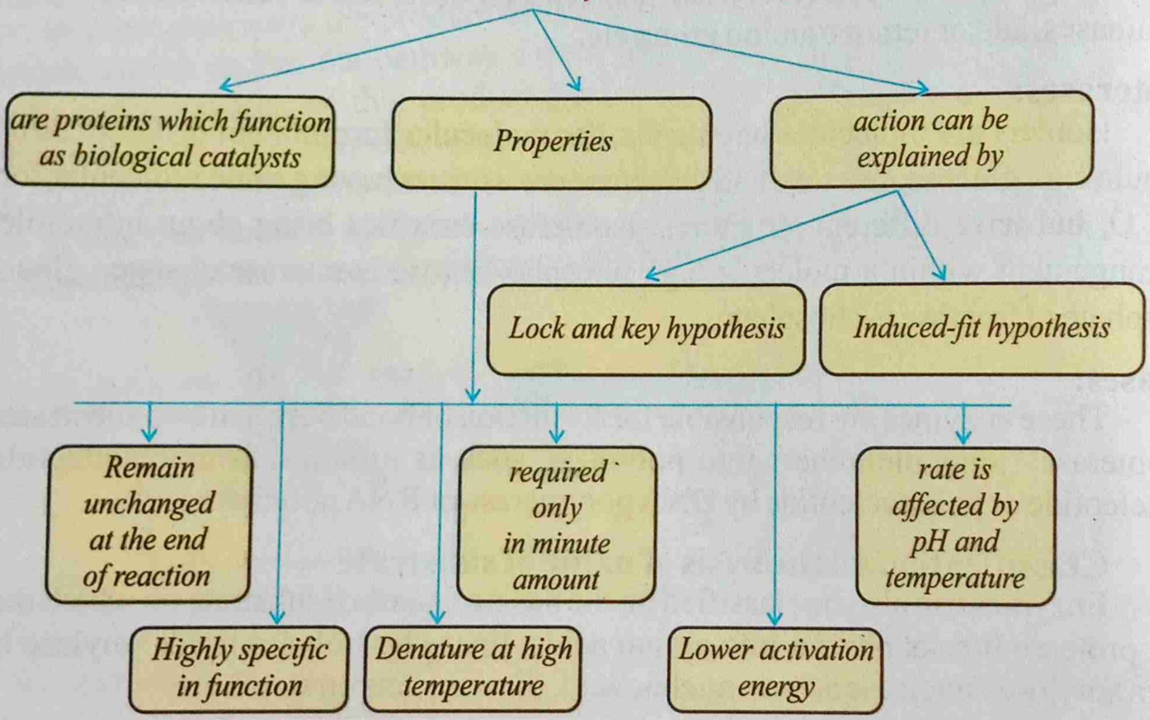
Table: 3.3 Comparison between Competitive and non-competitive enzyme inhibition

Competitive inhibition	Non-competitive inhibition
1- Example: succinate dehydrogenase is inhibited by malonate. 2- Inhibitor binds to active sites. 3- Inhibitor does not change the shape of the active site. 4- Increase in substrate concentration reduces the effect.	1- Example: pyruvate kinase is inhibited by alanine. 2- Inhibitor binds away from the active site i.e., at allosteric site. 3- Inhibitor changes the shape of the active site. 4- Increase in substrate concentration does not affect.

Do you know?

Germinating seeds have enzymes which convert insoluble stored food into simpler soluble substances for example the enzyme amylase digests starch and converts it into maltose.

Table 3.4 A Bird's eye view of Enzymes



Skills: Analyzing

Relate enzyme activity with antibiotics by searching internet and try to find out the reason why antibiotics are not effective against viruses.

Do you know?

Papain enzyme also known as papaya proteinase -1. It is a cystein protease present in papaya and mountain papaya. Active both in acidic and basic medium.

Industrial Enzymes

The commercial use of enzymes is increasing day by day due to the advancements of biological knowledge of enzymes .

The enzymes are used in variety of industries such a pharmaceuticals, chemical productions, Bio fuels, food and beverages industry and consumer products like Laundary detergents, products of cosmetics, meat tenderizers etc.

SUMMARY

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A. Choose the best correct answer.

1. A biochemical reaction would proceed at a very slow speed making life impossible in the absence of
   (a) Enzyme (b) Cofactor
   (c) Coenzyme (d) Substrate
2. An enzyme with its coenzyme or prosthetic group is called as
   (a) Holoenzyme (b) Apoenzyme
   (c) Activator (d) Inhibitor
3. Generally a single enzyme catalyzes only a single substrate or a group of related substrates, therefore, the enzymes are
   (a) Specific (b) Reactive
   (c) Activator (d) Inhibitor
4. The enzymes involved in cellular respiration are found in
   (a) Golgi bodies (b) Mitochondria
   (c) Chloroplast (d) Ribosomes
5. Every enzyme functions most effectively over a narrow range of pH known as
   (a) Maximum (b) Minimum
   (c) Optimum (d) Both a and b
6. Enzymes are sensitive to minor changes in
   (a) pH (b) Substrate concentration
   (c) Temperature (d) All of these
7. The chemical substance with which an enzyme reacts is called its
   (a) Substrate (b) Active site
   (c) Inhibitor (d) Cofactor
8. Enzymes require which medium for its activity.
   (a) Solid (b) Semi-solid
   (c) Aqueous (d) Jelly-like

9. The optimum temperature for enzymes in human body is
(a) 4°C (b) 37°C
(c) 41°C (d) 50°C

10. The catalytic activity of an enzyme is restricted to its small portion called
(a) Active site (b) Passive site
(c) Intermediate (d) Allosteric site

11. The reversible inhibitors usually constitute
(a) Strong linkage with enzyme (b) Weak linkage with enzyme
(c) No linkage with enzyme (d) Medium linkage with enzyme

B. Fill in the blanks.

1. The detachable cofactor of enzyme is called ....
2. Reversible inhibitors may be competitive or ....
3. The minimal amount of energy required to carry out a chemical reaction is called ....
4. Enzymes become denatured due to .... temperature .
5. The optimum pH of pepsin is ....
6. Induced fit hypothesis was proposed by .... in 1958.

Section II: Shorts Questions

Bioenergetics

Bioenergetics is the field of biochemistry and cell biology which deals with the study of the processes by which cells use, store and release energy. The quantitative study of energy relationships in biological system is called **bioenergetics**.

A central component of bioenergetics is energy transformation, the conversion of energy from one form to another. The biological energy transformations obey the laws of thermodynamics. Energy is necessary for growth and reproduction. We cannot exhibit

any of characteristics of life without a ready supply of energy. In this chapter we will discuss the most fundamental metabolic processes which are photosynthesis and respiration.

> **Tit bits**
>
> *An exergonic reaction is a spontaneous chemical reaction that releases energy. It is catabolic reaction. An endergonic reaction is an anabolic chemical reaction that consumes energy.*

4.1 Photosynthesis

Photosynthesis is the biological process that captures light (solar) energy and converts it into chemical energy (i.e. organic molecules, e.g., glucose). It takes place in plants, algae, cyanobacteria and many bacteria.

Photosynthesis is a "redox" process which links non-living world to the living world. It involves the reduction of carbon dioxide into sugars and the oxidation of water into molecular oxygen. The overall reactions of photosynthesis can be summarized as follows:

Reduction

$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

Oxidation

4.1.1 Role of Light in Photosynthesis

Light is a form of energy called **Electromagnetic energy or radiation**. Solar radiation is consist of photons. Photons (Gk. "*Phos*"=Light) are separate and distinct packets of energy which come from solar radiation. Photons travel in waves, these waves contain energy. Short waves contain more energy than long wave.

The full range of electromagnetic radiation in the universe is called **electromagnetic spectrum** while visible light (380-750 nm) is only a small part of the spectrum.

Visible light:

Visible light is the part of the spectrum that the human eye can see which is white light. Photons of visible light have just the right amount of energy to promote electrons to higher electron shell in atoms. Leaves absorb only 1% of total light, which falls on them, rest is reflected or transmitted. The synthesis of ATP from ADP or AMP is called phosphorylation which is endergonic process.

$$\textbf{ADP + Pi + energy} \rightleftharpoons \textbf{ATP}$$

In photosynthetic organisms the energy comes from light thus the process of formation of ATP during photosynthesis is referred to as **photophosphorylation.** Light falls on green tissues thereby water molecules are broken down (photolysis) into $\mathbf{H^+}$ ions, $\mathbf{OH^-}$ radicals and electrons. The $\mathbf{OH^-}$ radicals are collected and reassembled as water and molecular oxygen, both are released into

> **Do you know?**
>
> *Some carotenoids may protect chlorophyll and human eye from intense light by absorbing and dissipating excessive light energy.*

atmosphere. The Hydrogen ions (protons) are pumped across the thylakoid membrane into the lumen. H^+ ions are used to convert NADP to $NADPH_2$ in photosystem I.

4.1.2 Role of Photosynthetic Pigments

A photosynthetic pigment is a pigment that is present in chloroplasts or photosynthetic bacteria and captures the light energy necessary for photosynthesis. Different pigments absorb light of different wavelengths. The light appear in different colours when passed through a prism.

Carotenoids:

These are a group of yellow, orange, red or brown pigments that absorb blue, violet and green light. They are associated with the chlorophyll inside the chloroplast or occur alone inside the chloroplast. Carotenoids absorb different wavelengths than chlorophyll, so broaden the spectrum of light that provides energy for photosynthesis. The chlorophyll *b* and carotenoids together are called accessory pigments because they absorb light and transfer the energy to chlorophyll *a* which then starts the light reaction.

Tit bits

Carotenoids in flowers and fruits attract insects, birds and other animals for pollination and seed dispersal respectively. They also protect chlorophyll from oxidation by oxygen produced in photosynthesis.

Carotenoids $\longrightarrow$ Chlorophyll *b* $\longrightarrow$ Chlorophyll *a*

Chlorophylls:

Chlorophylls are green and main photosynthetic pigments which absorb violet, blue, orange and red wavelengths, while green and yellow are least absorbed and are reflected (therefore, leaves look green). There are six types of chlorophylls (*a, b, c, d, e,* and *f*) out of these only two types occur in chloroplasts of higher plants, i.e. chlorophyll *a* and *b*. Chlorophyll *c* and *d* are found only in algae while chlorophyll *e* and *f* are found only in bacteria.

Do you know?

There are two types of carotenoids, i.e. Carotenes and Xanthophylls.

Carotenes (Red to Orange):

Carotenes are hydrocarbons with a general formula of $C_{40}H_{56}$. Red colour of tomato and chilli are due to carotenes. The most common carotene is beta-carotene which is converted to vitamin A by animals and human beings.

Xanthophylls (Yellow to Orange):

Xanthophylls are yellow pigments that are oxygen containing derivatives of carotenes. Lutein and zeaxanthin ($C_{40}H_{56}O_2$) are the two primary xanthophylls found in green leafy vegetables and other foods like eggs. Yellow colour of leaves in autumn is due to lutein.

The xanthophylls of brown algae is called fucoxanthin ($C_{40}H_{56}O_6$). Both carotenes and xanthophylls are lipid compounds, soluble in organic solvents like other lipids.

Chlorophyll *a*:

It occurs in all photosynthetic organisms except pigmented bacteria thus termed as universal photosynthetic pigment. It is also known as primary photosynthetic pigment because it involves in primary reaction during photosynthesis, i.e. convert light energy into chemical energy. Molecular formula of chlorophyll *a* is ($C_{55}H_{72}O_5N_4Mg$).

Chlorophyll *b*:

Chlorophyll *b* occurs in all photosynthetic organisms except brown, red and blue green algae. Molecular formula of chlorophyll *b* is ($C_{55}H_{70}O_6N_4Mg$).

Structure of Chlorophyll:

Each chlorophyll molecule has two main parts, one flat square part which absorbs light and hydrophilic head. The other part is long anchoring hydrophobic carbon tail.

The head of chlorophyll is composed of four pyrrole rings (pyrrole is five sided unsaturated nitrogen containing compound) having Mg^{++} in the center, thus it is Mg^{++} **porphyrin** with two side chains.

> **Do you know?**
>
> *Porphyrin is derivative of porphin, consists of four pyrrole like rings linked by four CH groups in an alternate double and single bonds. If Mg++ or Fe++ are added to porphin then known as Mg++ porphyrin in chlorophyll or Fe++ porphyrin in Heme and cytochrome.*

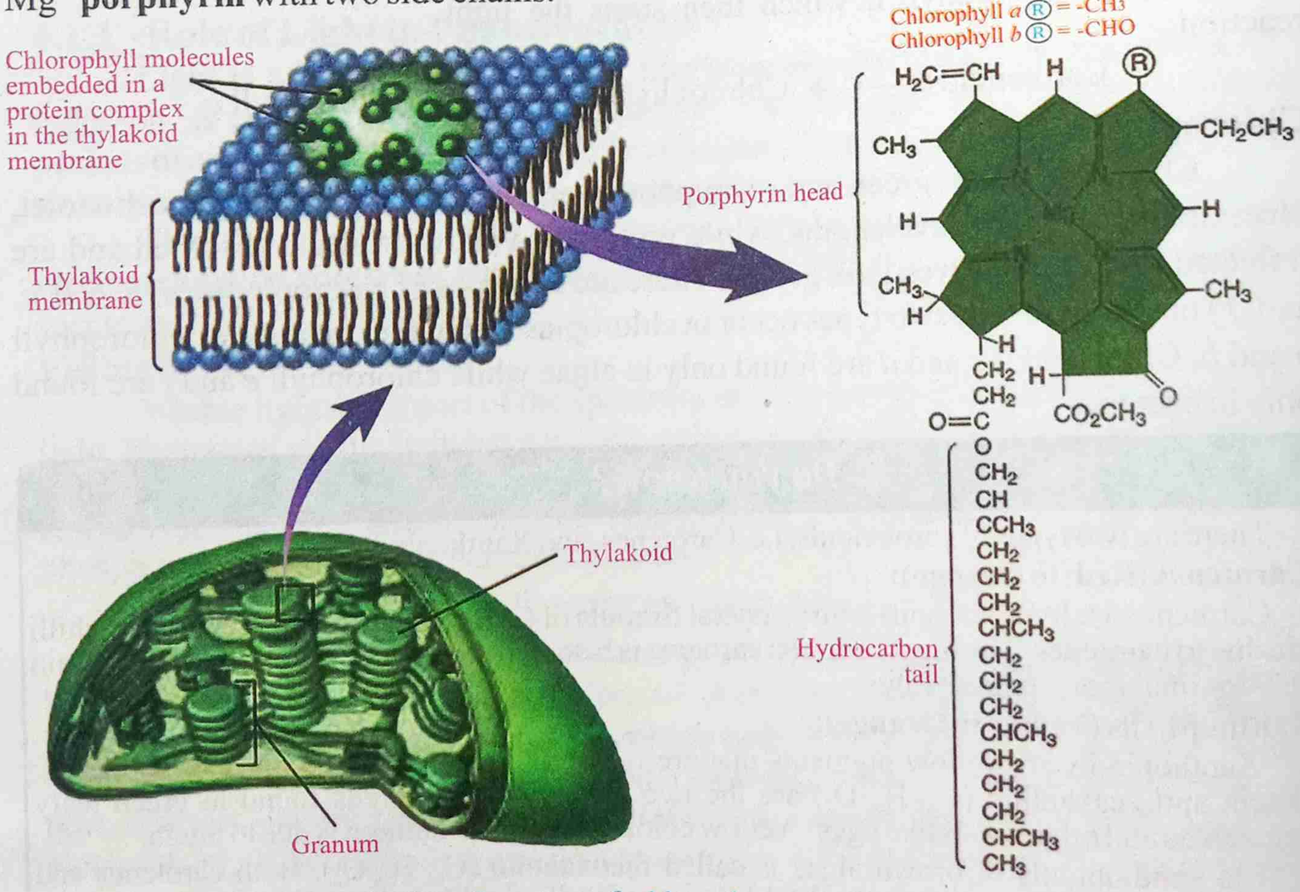


Fig. 4.1 Structure of chloroplast and chlorophyll

a. **Acid chain:** It is a methyl (CH_3) ester ($H_3C–O–C=O$).

b. **Hydrocarbon chain:** It is a long hydrocarbon tail which is attached to one of the pyrrole rings and is an alcohol phytol ($C_{20}H_{39}$) (it is an ester linkage with propionic acid) (CH_3-CH_2-COOH).

Phytol consists of four isoprene units. It is insoluble and serves to anchor the molecule in the membrane of the granum (molecular formula of isoprene is ($CH_2=C-CH_3-CH=CH_2$) (C_5H_8).

Differences Between Chlorophyll *a* And *b*:

There is only one difference between chlorophyll *a* and *b* that is one of functional group bonded to the porphyrin. In chlorophyll *a* methyl group (CH_3) while in chlorophyll *b* aldehyde group (-CHO) is present.

Role of Pigments in Photosynthesis

The clusters of photosynthetic pigments are called photosystem. Each pigment complex is composed of chlorophyll *a* and *b* molecules with accessory pigments. When these pigments absorb light they are said to be excited. The light energy is used to boost electrons to a higher energy level which is transferred into chemical energy. The excited state is unstable and molecules will tend to return to its unexcited state.

The energy which is released during this process can be passed from one chlorophyll molecule to another chlorophyll molecule. The instrument which is used to measure relative abilities of different pigments to absorb different wavelength of light is called **Spectrophotometer**.

4.1.3 Absorption Spectrum

It is a measure which exhibits the absorbed amount of the light of different wavelengths (different colours) from the visible spectrum of light. The main photoreceptors are chlorophyll *a* and chlorophyll *b* which absorb violet blue (430 nm) and red light (670 nm). The green light (550 nm) is least absorbed. The carotenoids absorb light between 430-470 nm of light spectrum and transfer it to chlorophyll *b* then to chlorophyll *a*. The chlorophyll *a* and *b* show different absorption spectra as shown figure 4.2 (a). Chlorophyll *a* shows absorption peaks at about 680 and 700 nm while chlorophyll *b* absorption peaks range between 450-475 nm.

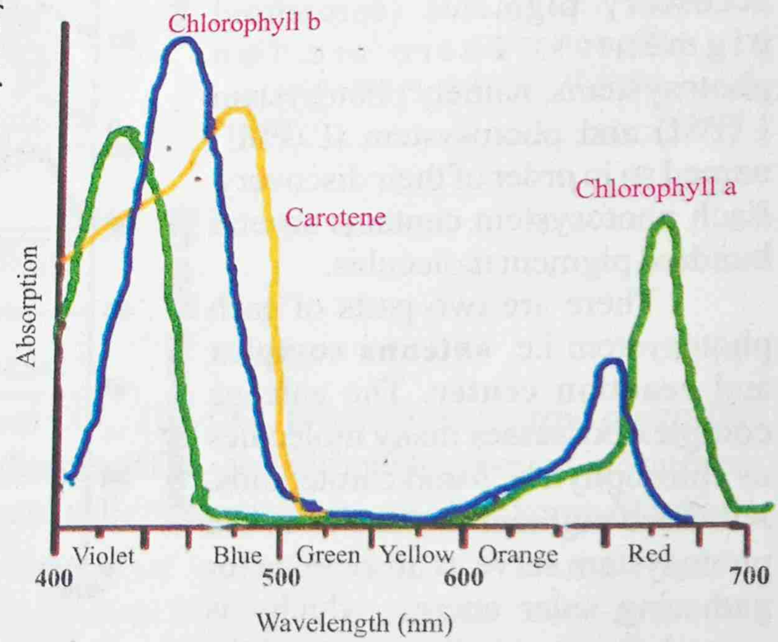


Fig. 4.2 (a) Absorption Spectra

4.1.4 Action Spectrum

A graph showing the measure of effectiveness of light of various wavelengths in driving photosynthesis is called action spectrum. Some of absorbed light is released as heat and rest of light is stored in organic compound as chemical energy. Action spectrum of a particular pigment can be calculated by measuring the rate of photosynthesis at each type of wavelength of light. A plant is illuminated with light of different wavelengths. During photosynthesis plant gives off oxygen. As photosynthesis produces oxygen and consumes CO_2, the rate of production of oxygen or consumption of CO_2 can be used as a measure of the rate of photosynthesis.

Do you know?

Accessory pigments are photosynthetic pigments that trap light energy and channel it to chlorophyll "a" the primary pigment which initiates the reaction of photosynthesis. Accessory pigmants are carotenoids, phycobilin, some proteins and chlorophyll b,c and d.

4.1.5 Arrangement of Photosynthetic Pigments in the form of Photosystem I and II

Light reaction takes place in the grana of chloroplast. It is initiated when photosynthetic pigments capture light energy. The clusters of photosynthetic pigment complex are composed of chlorophyll *a* and *b* molecules and accessory pigments (carotenoid pigments). There are two photosystems, namely photosystem I (PSI) and photosystem II (PSII) named so in order of their discovery. Each photosystem contains several hundred pigment molecules.

There are two parts of each photosystem i.e. **antenna complex** and **reaction center**. The antenna complex possesses many molecules of chlorophyll *a*, *b* and carotenoids. All these pigment molecules in the photosystem serve as an antenna for gathering solar energy, which is passed from one pigment to the other and finally transferred to the

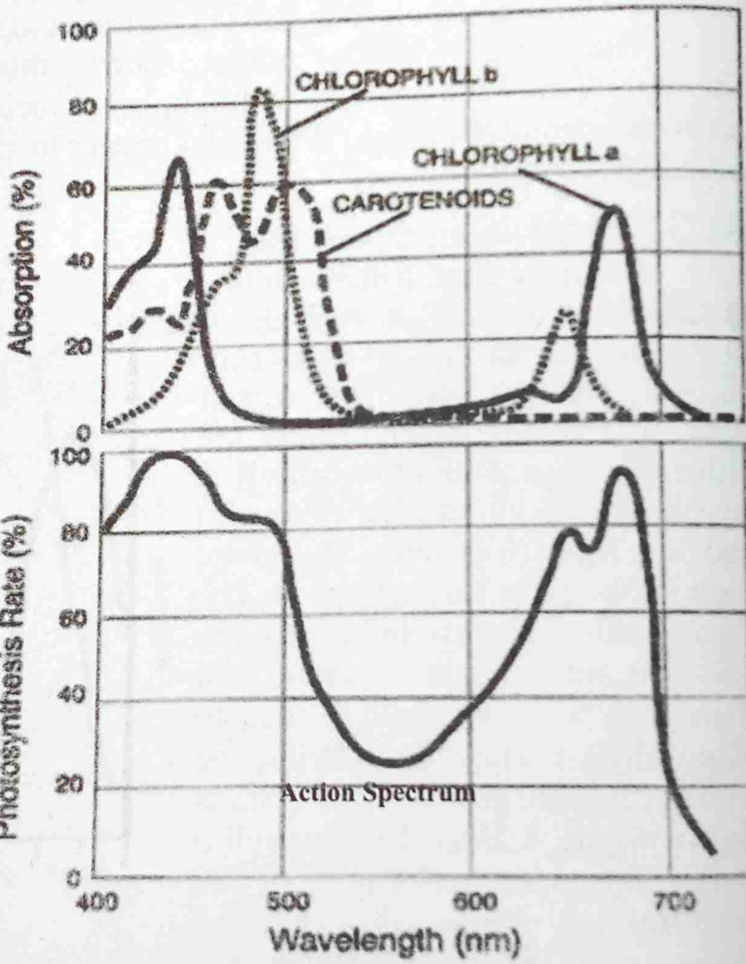


Fig. 4.2 (b) Absorption and Action spectra of different pigments

reaction center. **Reaction center** contains one more molecule of chlorophyll *a* alongwith primary electron acceptor and electron carriers of electron transport system. Electron transport system plays a role in the generation of ATP by **chemiosmosis.** The PSI absorbs light of 700 nm and is called P700 while the PSII absorbs light of P680 nm and is called P680. The **primary electron acceptor** traps the electrons from the reaction center and then passes them on to the series of electron carriers. Electrons have two pathways in the light reaction of photosynthesis; The non-cyclic electron pathway (flow) and cyclic electron pathway. The cyclic is less common and generates only ATP while non-cyclic is predominant and generates both ATP and $NADPH_2$.

Do you know?

The action spectrum is somewhat different from absorption spectrum of chlorophyll. It is more in some wavelengths, such as in 500-600 nm is more than the absorption of green light by chlorophyll. This is because the carotenoids absorb light in this region and pass on some of this absorbed light to chlorophyll, which converts light energy into chemical energy. Similarly when equal intensities of light are given, there is more photosynthesis in red than in blue part of the spectrum.

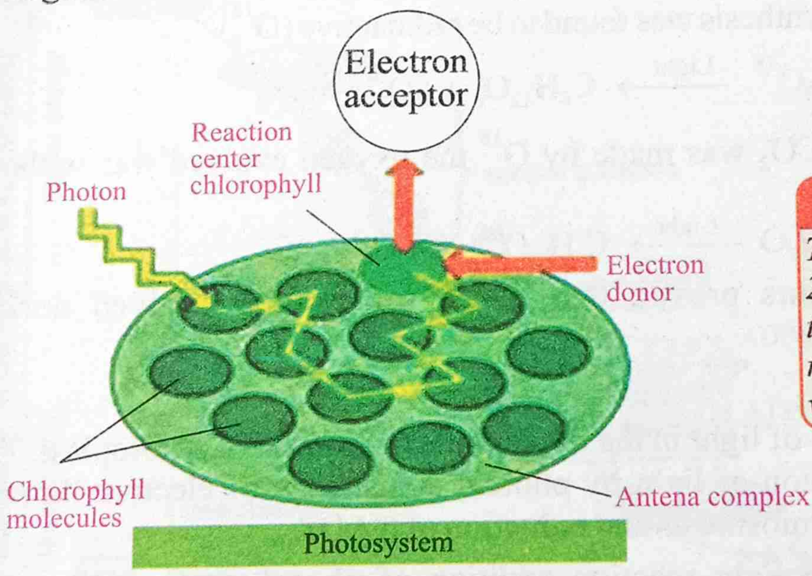


Fig. 4.3 Structure of Photosystem

Thinking Question

The stomata cover only I to 2% of the leaf surface but they allow proportionally much more gas to diffuse, why?

4.1.6 Role of CO_2 in Photosynthesis

Air contains about 0.03 to 0.04 % of CO_2. This CO_2 is used by terrestrial plants for photosynthesis while aquatic plants use dissolved CO_2 and carbonates present in water as source of carbon. The chloroplasts of guard cells of stomata absorb CO_2, some of which react with water to form carbonic acid.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

In the presence of solar energy carbonic acid in the guard cells is decomposed again into water and CO_2.

$$H_2CO_3 \longrightarrow H_2O + CO_2$$

Water and carbondioxide are rapidly used in photosynthesis to synthesize organic substances. The entry of CO_2 into the leaves depends upon the opening of stomata.

4.1.7 Role of Water in Photosynthesis

Water is one of the raw materials used in photosynthesis. A film of water present around mesophyll cells of leaf helps to absorb CO_2. The water molecule is broken down into hydrogen and oxygen by the P_{680} during **photolysis**. The hydrogen combines with CO_2 to form organic food and molecular oxygen is released into atmosphere during photolysis of H_2O. Earlier it was thought that the oxygen released in the process of photosynthesis comes from CO_2. Van Neil 1903, was first who observed that water splits during photosynthesis, hydrogen released from water is used to synthesize glucose while O_2 is removed as byproduct. The idea of Van Neil was also supported by another scientist named Hill. In first experiment water was made of O^{18} and algae were grown in it. The oxygen evolved during photosynthesis was found to be radioactive (O^{18}).

> **Tit bits**
>
> *Photolysis is the splitting of a chemical compound by means of light energy i.e., photons e.g., photolysis of water in photosynthesis produces H^+ and O_2.*

$$6CO_2 + 12H_2O^{18} \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6O_2^{18} + 6H_2O$$

In second experiment CO_2 was made by O^{18} the oxygen evolved was without isotope.

$$6CO_2^{18} + 12H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6^{18} + 6H_2O^{18} + 6O_2$$

Thus above experiments proved that source of oxygen evolved during photosynthesis was water.

4.1.8 Light Reaction

It occurs in the presence of light in the thyllakoids of granum of chloroplast. The light reaction involves absorption of light by photosystems, flow of electron through electron transport chain i.e. chemiosmosis and reduction of NADP.

Photophosphorylation: In light reaction addition of phosphate to ADP in the presence of light is called photophosphorylation. There are two pathways:

(i) Cyclic photophosphorylation (ii) Non Cyclic photophosphorylation

Cyclic Photophosphorylation: The cyclic photophosphorylation is less common and generates only ATP while non-cyclic photophosphorylation is predominant and generates both ATP and $NADPH_2$.

Non-Cyclic Photophosphorylation: During non-cyclic photophosphorylation electrons move from water through PS-II to PS-I then to NADP.

Photosystem II:

When light strikes the chlorophyll molecules in PSII (p680) its energy causes the

chlorophyll molecule to be activated. The activated chlorophyll loses its two electrons and the positively charged chlorophyll molecule is left in the photosystem with a gap of two electrons. The high energy electrons instead of falling back into the photosystem are captured by primary electrons acceptor of first electron transport chain. The **primary electron acceptor is pheophytin** which then passes the electrons to a plastoquinone (PQ). Now from primary electrons acceptor, the electrons pass along a series of electron acceptor molecules from one to another in oxidation process. These electron acceptors are two **cytochromes** (cytochrome *b* and *f*) and **plastocyanin** (PC) (a copper containing protein).

Production of ATP:

When electrons are passed through electron transport chain, they lose energy. Some of the energy lost by electrons between cytochrome *b* and cytochrome *f* is used to make ATP from ADP and Pi. This ATP, which is generated by PS-II will provide energy for Calvin cycle where CO_2 is fixed to synthesize sugar.

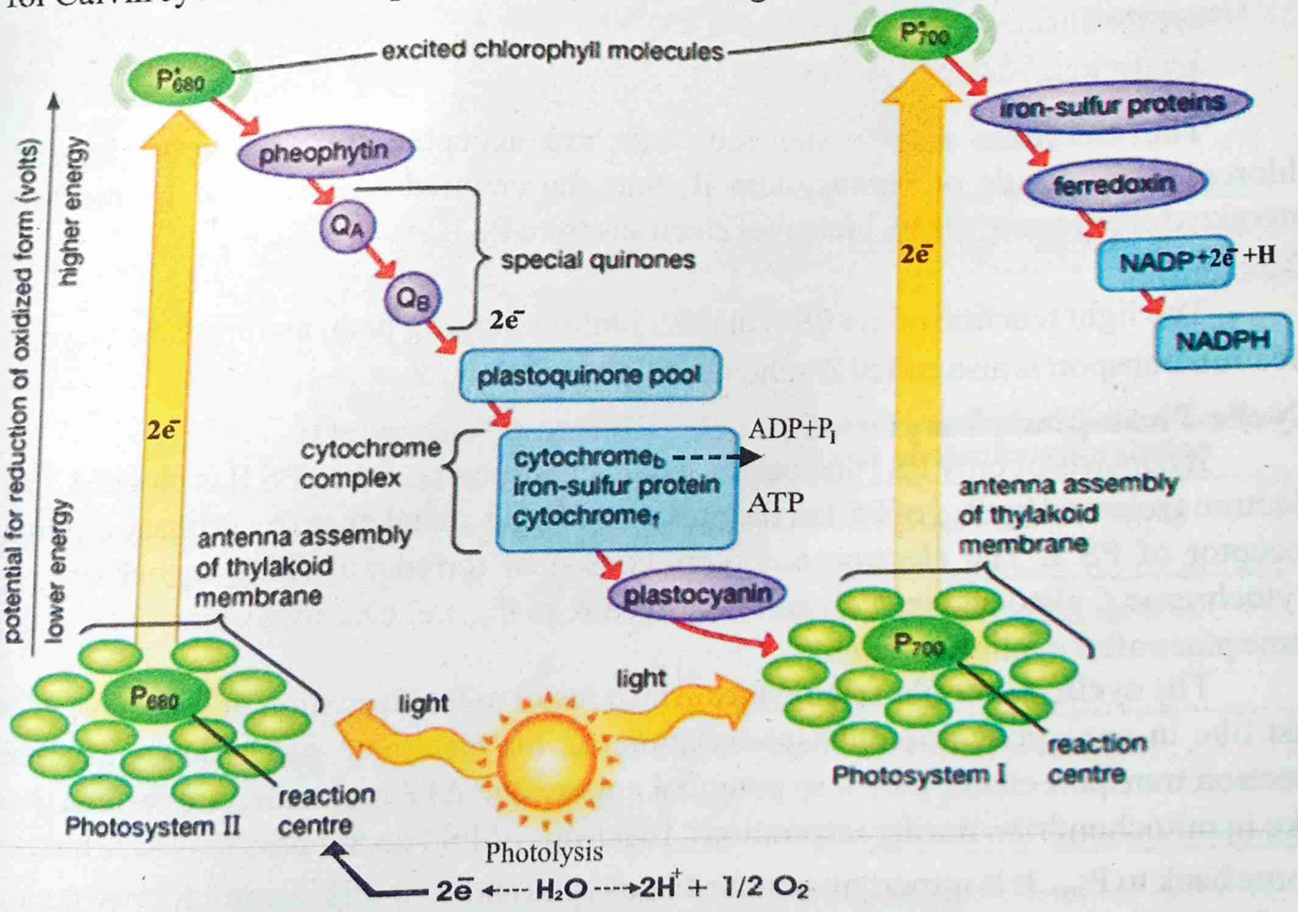


Fig. 4.4 Non- cyclic photophosphorylation (Z-scheme)

Activity

1. *Why do we consider the leaves in plants as food factories?*
2. *Trace out the environmental factors that affect the rate of photosynthesis?*

Photosystem I:

The electrons from PS II pass to PS I. The electrons from plastocyanin are received by another photosystem called photosystem I (P_{700}), where these electrons are boosted to high energy state by absorbing a photon of light.

The photoexcited electron of PS I enters in the second electron transport chain. Here electrons are accepted by ferredoxin (FD), which is also an iron containing protein. The enzyme NADP reductase (flavo protein enzyme) by a redox reaction transfers the electrons from ferredoxin to NADP. The NADP combines with electrons and hydrogen to form $NADPH_2$.

ATP and NADPH are used in Calvin cycle to produce sugar.

$$NADP^+ + 2e^- + 2H^+ \longrightarrow NADPH + H^+$$

When photosystem II absorbs light water molecule splits into **OH^-** and **H^+**. The **OH^-** ions react to form some water and release oxygen and electrons.

$$4H_2O \longrightarrow 4H^+ + 4(OH^-) + 4e^-$$

$$4(OH^-) \longrightarrow 2H_2O + O_2$$

The electrons from water molecule are accepted by positively charged chlorophyll molecule of photosystem II, thus the emptied hole is filled by the two energized electrons while PS I receives electrons from PS II.

Z-Scheme:

The light reaction of the PS II and PS I follows zigzag path, therefore, non-cyclic electron transport is also called Z-scheme of light reaction.

Cyclic Photophosphorylation (Cyclic Electron Transport):

It consists of only PS I and occurs in rare condition i.e. when PS II is blocked. The electrons released by P_{700} of PS I in the presence of light are taken up by primary electron acceptor of PS I. The electron acceptors consist of ferredoxin (FD), cytochrome *b*, Cytochrome *f*, plstocyanin (PC) and finally back to P_{700} i.e. electrons come back to the same place after cyclic movement.

The **cyclic photophosphorylation** also result in the formation of ATP molecules just like in non-cyclic photophosphorylation. As the electrons move downhill in the electron transport chain, they lose potential energy and ATP molecules are formed (just like in mitochondrion during respiration). Electrons of PS I do not pass to NADP instead come back to P_{700}. It is important to note that oxygen and $NADPH_2$ are not formed during cyclic photophosphorylation.

Which conditions lead to cyclic electron pathway?

1. When production of ATP is low thus Calvin cycle does not begin.
2. Due to slow rate of Calvin cycle, $NADPH_2$ do not oxidize into NADP.

3. There are many other enzymatic reactions which use ATP in stroma, thus Calvin cycle becomes slow.
4. Limited supply of CO_2 also affects carbohydrate synthesis .

Summary of Light Reactions:

Requirements:

1. Light
2. Enzymes needed for different reactions in the chloroplast
3. H_2O
4. NADP
5. ADP and Pi (inorganic phosphate)

Products:

1. Oxygen
2. ATP
3. $NADPH_2$

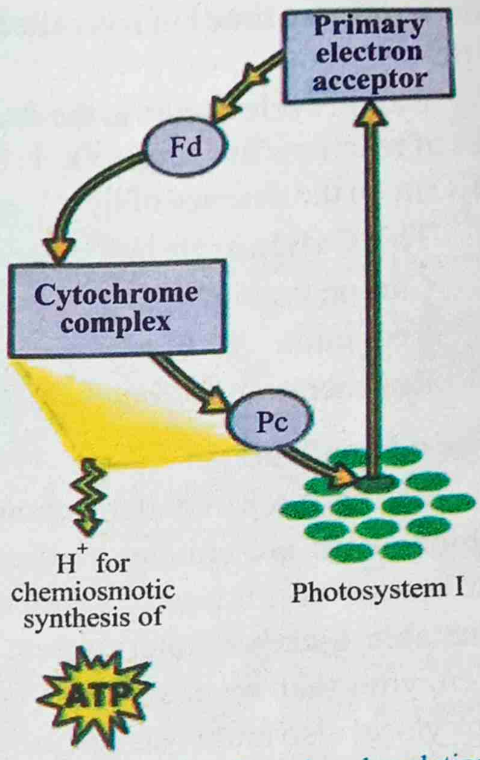


Fig. 4.5 Cyclic photophosphorylation

Activity

1. Draw the Z-scheme for explaining the events of light dependent reactions.
2. Draw the labelled structure of chloroplast.

Table 4.1 Comparison between cyclic and non-cyclic photophosphorylation

Non-cyclic photophosphorylation	Cyclic photophosphorylation
Elections do not come back to the same molecule.	Electrons come back to the same molecule.
First electron donor is water.	First electron donor is P_{700} (PS I).
Involves both PS I and PS II.	Involves PS I only.
Last electron acceptor is NADP.	Last electron acceptor is (P_{700}).
The net products are ATP, $NADPH_2$ and O_2.	The Product is ATP only.

4.1.9 Light Independent Reaction or Dark Reaction

The light independent reaction was discovered by Melvin Calvin and coworkers (1950) at the University of California. He was awarded Noble prize in 1961 for his work. Therefore, this cycle is also called **Calvin cycle.** They used radioactive isotope of C^{14} in CO_2 . Light independent reactions do not need direct energy of sunlight. It may

occur during day time but it is called dark reaction, so as to differentiate it from the light reaction.

Calvin cycle occurs in the stroma of chloroplast by a series of reactions in which CO_2 is fixed into carbohydrate **$(CH_2O)n$** in the absence of light.

The **Calvin cycle** is completed in three stages:

i) Carbon fixation

ii) Reduction

iii) Regeneration of ribulose bi-phosphate.

Do you know?

Rubisco is the most abundant protein on earth.

Do you know?

Oxidation is the loss of electron from an atom or molecule while reduction is the gain of electrons by an atom or molecules.

Tit bits

9 ATP and 6 $NADPH_2$ from light reaction are used in Calvin cycle to produce one PGAL, which can be used to form glucose, fructose etc.

Carbon Fixation:

It is first step of dark reaction in which **CO_2** from air combines with pre-existing five carbon phosphorylating sugar known as ribulose biphosphate (RuBP). As a result an unstable 6-carbon intermediate compound is formed. The enzyme that speeds up this reaction is called RuBP carboxylase; also known as **Rubisco**.

The six carbon intermediate molecule exists for such a brief time that it cannot be isolated and thus named as an intermediate compound.

Formation of PGA:

The unstable intermediate compound splits into two molecules of three carbon containing phoshoglyceric acid (PGA). It is first identifiable product in dark reaction. Therefore, Calvin cycle is also called **C_3 Cycle**.

$$CO_2 + RuBP(C_5) \longrightarrow C_6 \text{ (intermediate compound)} \longrightarrow 2\,PGA(C_3)$$

The carbon that was part of CO_2 molecule is now a part of organic molecule. This is called CO_2 fixation.

Reduction (Formation of PGAL or G3P):

In this step the product of light reaction that is ATP and $NADPH_2$ are used. Each molecule of phosphoglyceric acid (PGA) receives energy from ATP and H^+ from $NADPH_2$ forming 3 carbon phosphoglyceraldehyde (PGAL). In this step water is also formed. In reduction process fixed carbon is reduced into a 3-carbon sugar molecule of PGAL.

$$PGA + ATP + NADPH_2 \longrightarrow PGAL + ADP + Pi + NADP + H_2O$$

ADP and Pi and NADP return back to light reaction where ADP is converted into ATP and NADP is reduced into $NADPH_2$.

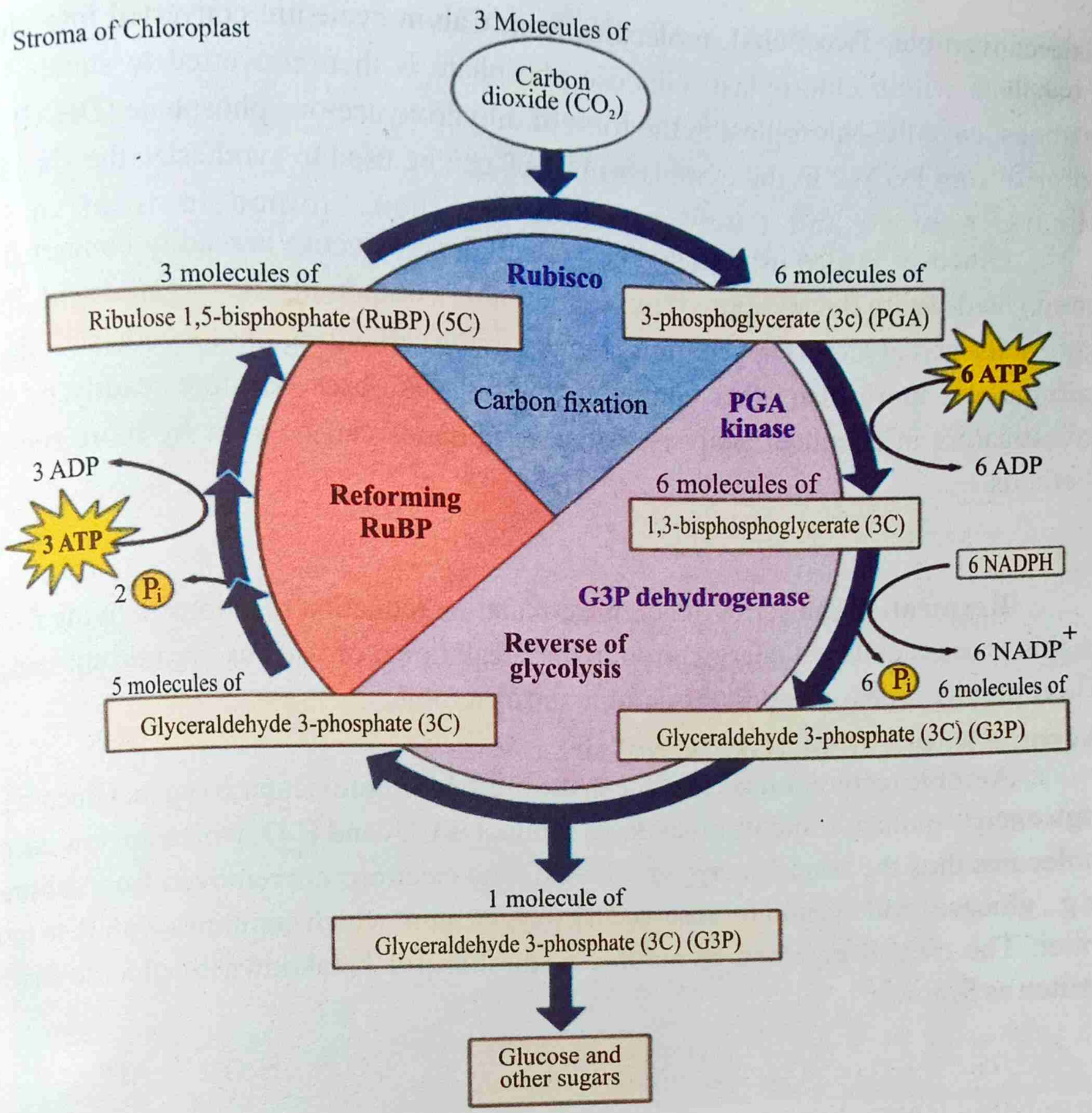


Fig. 4.6 Calvin cycle

Regeneration of RuBP (Formation of glucose and other organic compounds):

For every turn of Calvin cycle five molecules of PGAL are used to reform three molecules of RuBP, so that cycle can continue. It also uses ATP of light reaction.

$$5\ PGAL + ATP \longrightarrow ADP + Pi + 3\ RuBP$$

Thus out of every six molecules of PGAL formed in the reduction stage, only one molecule leaves the cycle, which is to be used by plant for making glucose and other organic compounds.

Use of PGAL

From PGAL 3C, 4C, 5C, 6C and 7C compounds are produced, all are

interconvertible. Two PGAL molecules from Calvin cycle are converted into glucose phosphate within chloroplast. Glucose phosphate is then converted to starch. Fixed carbons leave the chloroplast in the form of dihydroxyacetone phosphate (DHAP). It is formed from PGAL. In the cytoplasm DHAP can be used to synthesize the six carbon sugars, glucose and fructose, which are then joined to form sucrose.

Glucose is also used to synthesize cellulose. Glucose is readily converted into amino acids (with the addition of nitrogen). Other compounds like organic acids that is fatty acids and glycerols appear quite rapidly in the cell during photosynthesis. Glucose accumulates more than other compounds, so it was observed more readily by early investigators in chemical analysis. Other compounds can be seen by more sensitive methods.

4.2 Cellular Respiration

Respiration is a series of complex oxidation reduction reactions in living things. In this process cells get energy through the break down of various organic substances. There are two types of respiration aerobic and anaerobic.

Aerobic Respiration: (Gk. "*Aeros*" air)

Aerobic respiration takes place in the presence of molecular oxygen. Glucose is a high energy molecule and its breakdown product is CO_2 and H_2O, which are low energy molecules thus the stored energy is released. The electrons are removed from substrate (e.g., glucose) and eventually received by oxygen atom which combines with H^+ to form water. The overall equation of aerobic respiration for breakdown of glucose can be written as follows:

$$C_6H_{12}O_6 + 6O_2 + 36ADP + 36Pi \xrightarrow{\text{Enzymes}} 6CO_2 + 6H_2O + 36ATP$$

Anaerobic Respiration:

Anaerobic respiration takes place in the absence of molecular oxygen, it is also known as **fermentation**. It is incomplete oxidation reduction reaction. The energy released from the substrate (glucose) is a result of its molecular rearrangement and some of this energy is available to the cell. The NADH is oxidized to NAD, it is called fermentation because glycolysis is followed by the reduction of pyruvate by NADH to either alcohol and CO_2 or lactate.

Alcoholic Fermentation:

In primitive cells and cells of some eukaryotic organisms such as yeast and plants, pyruvate is further broken down by alcoholic fermentation into alcohol and CO_2.

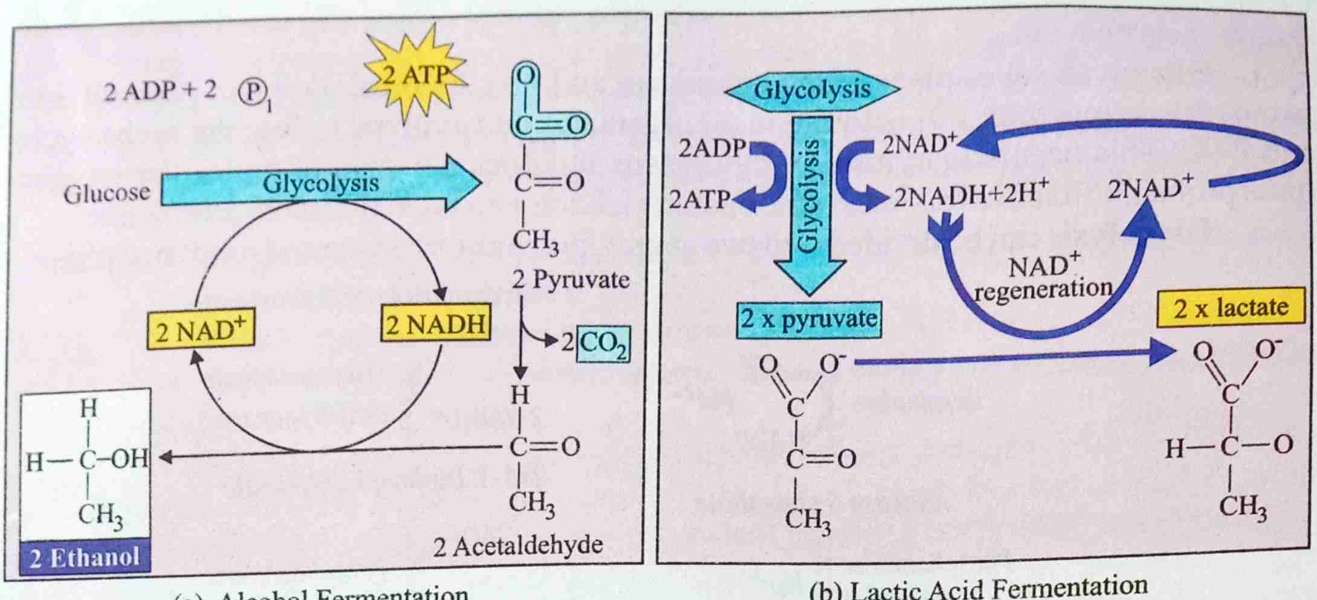


Fig. 4.7 Fermentation

Lactic Acid Fermentation:

It takes place in many bacteria, animals and muscles of human. Each pyruvate molecule is converted into lactic acid in the absence of molecular oxygen.

Process of cellular respiration:

It takes place in four steps.

1. Glycolysis
2. Oxidation of pyruvic acid
3. Krebs cycle
4. Electron transport chain

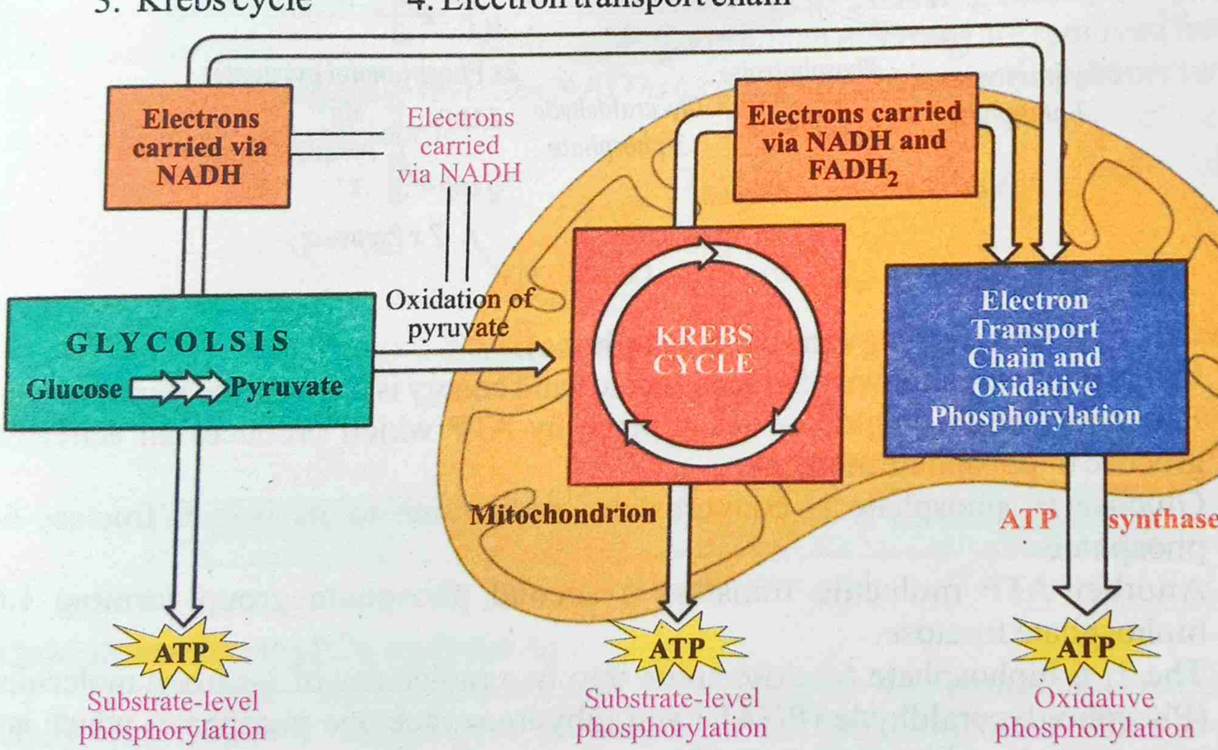


Fig. 4.8 Process of cellular respiration

4.2.2 Glycolysis

Glycolysis takes place in the cytoplasm and it is the break down of glucose into two pyruvate molecules. It is found in all organisms and evolved before the krebs cycle and ETC. This occurs in cytosol of cytoplasm and does not require molecular oxygen (thus probably first life was anaerobic bacteria). Each step is catalyzed by an enzyme. **Glycolysis** can be divided into two stages, preparatory phase and oxidative phase.

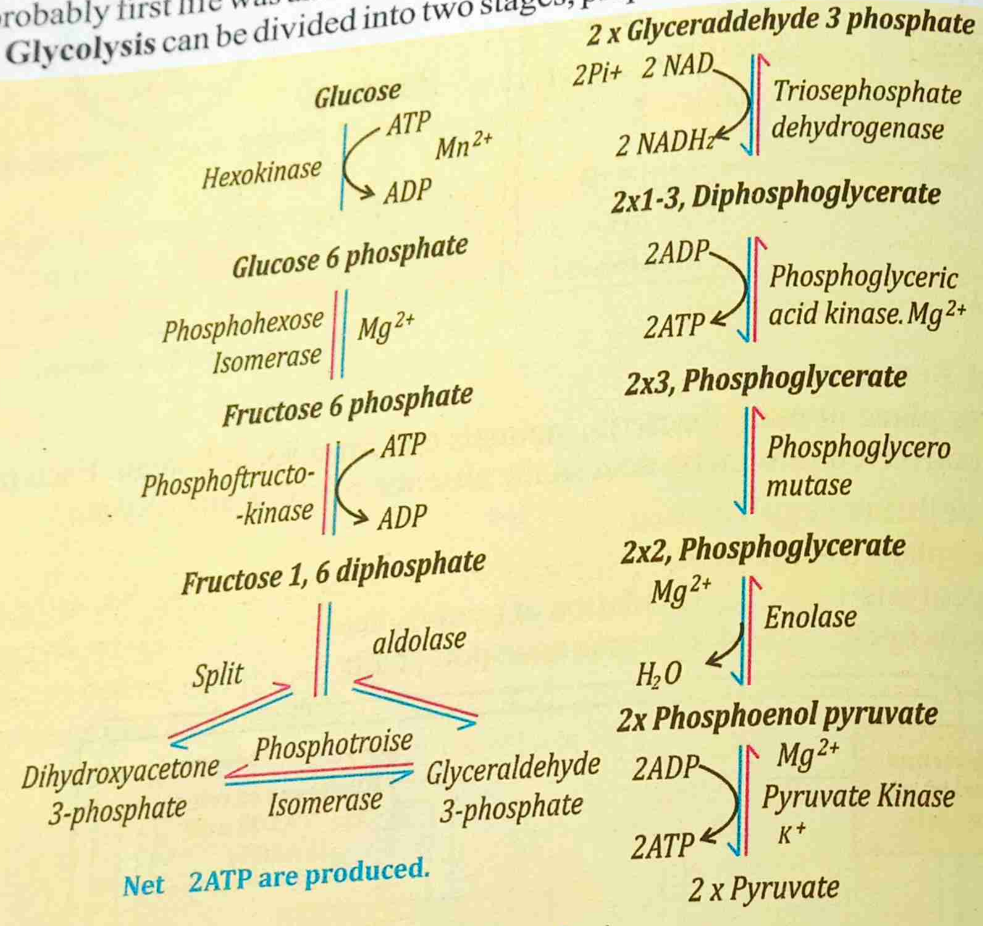


Fig. 4.9 . Glycolysis

Preparatory Phase (energy investment phase):

In this phase breakdown of glucose occurs and energy is utilized, the steps are:

1. Phosphorylation of glucose takes place by ATP which produces an activated glucose 6- phosphate molecule.
2. Glucose 6- phosphate is converted by an enzyme to its isomer fructose 6- phosphate.
3. Another ATP molecule transfers a second phosphate group forming 1,6 biphosphate fructose.

The 1, 6 biphosphate fructose splits into two molecules of 3-carbon molecules (Phosphoglyceraldhyde (PGAL) and dihydrooxyacetone phosphate) which are isomers and readily interconvertible.

Oxidative Phase (Energy yielding phase):

1. Two electrons or two hydrogen atoms are removed from the molecule of PGAL which is oxidized and these electrons are transferred to a molecule of NAD which is reduced. Inorganic phosphate is present in the cell, from which a second phosphate is donated to the molecule forming 1,3 bi or diphosphoglycerate (BPG or DPG).
2. DPG is converted to 3 phosphoglycerate (3-PGA). Meanwhile a phosphate bond is transferred from DPG to ADP forming ATP.
3. 3 PGA is converted to 2 phosphoglycerate (2PGA).
4. From 2 PGA a molecule of water is removed and phosphoenol pyruvate (PEP) is formed.
5. PEP then gives up its high energy phosphate which converts ADP to ATP. The product is pyruvate or pyruvic acid ($C_3H_4O_3$). It is equivalent to half glucose molecule that has been oxidized to the extent of losing two electrons as hydrogen atoms.

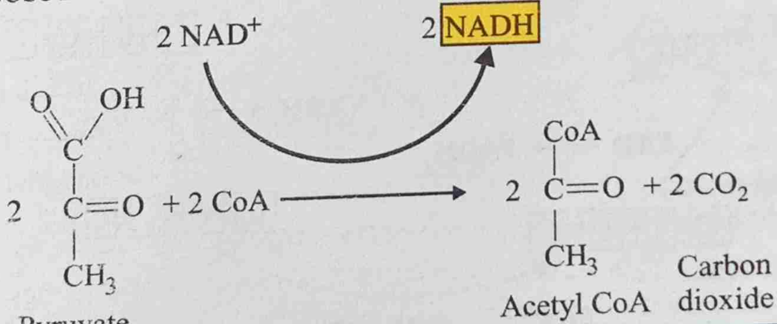
4.2.3 The Oxidation of Pyruvic Acid

It takes place into two stages.

1. Oxidation of pyruvic acid to form Acetyl Coenzyme A.
2. Oxidation of Acetyl Coenzyme A.

Oxidation of Pyruvic Acid:

It is a transition reaction during which CO_2 is released. The oxidation of pyruvic acid is called **transition reaction** because it connects glycolysis and krebs cycle. In this reaction pyruvate is converted to 2-carbon acetyl Co A by attaching coenzyme A. It gives off carbon dioxide. This is an oxidation reaction in which electrons are removed from pyruvate by dehydrogenase that uses NAD as a coenzyme. This reaction occurs twice for each original glucose molecule.



2 Pyruvate + 2 CoA ⟶ 2 Acetyl CoA + 2 Carbon dioxide

Fig. 4.10 Oxidation of Pyruvic Acid

Oxidation of Acetyl Co enzyme A:

It takes place through krebs cycle. As a first step 4-C compound oxaloacetate binds with 2-carbon acetyl CoA to become 6-carbon compound. This 6-carbon

compound passes through a series of electron yielding oxidation reactions. Two carbon dioxide molecules are given off. Finally regenerating 4-carbon compound which is free to bind another acetyl Co A. This cycle is called citric acid cycle or krebs cycle.

> **Do you know?**
> *Krebs cycle is also called Tricarboxylic acid cycle because each of its first three reaction has three molecules of carboxylic acid.*

4.2.4 Citric Acid Cycle or Krebs Cycle

This is cyclic metabolic pathway located in the matrix of mitochondria. The krebs cycle was named after Sir Hans krebs a British scientist who discovered it in 1930.

Steps of the Krebs cycle:

1. At the start of this cycle the (2-C) acetyle group (produced by transition reaction) joins with a (4-C) oxaloacetate molecule, forming 6-carbon citrate molecule.
2. Citrate is converted to an isomer called isocitrate.

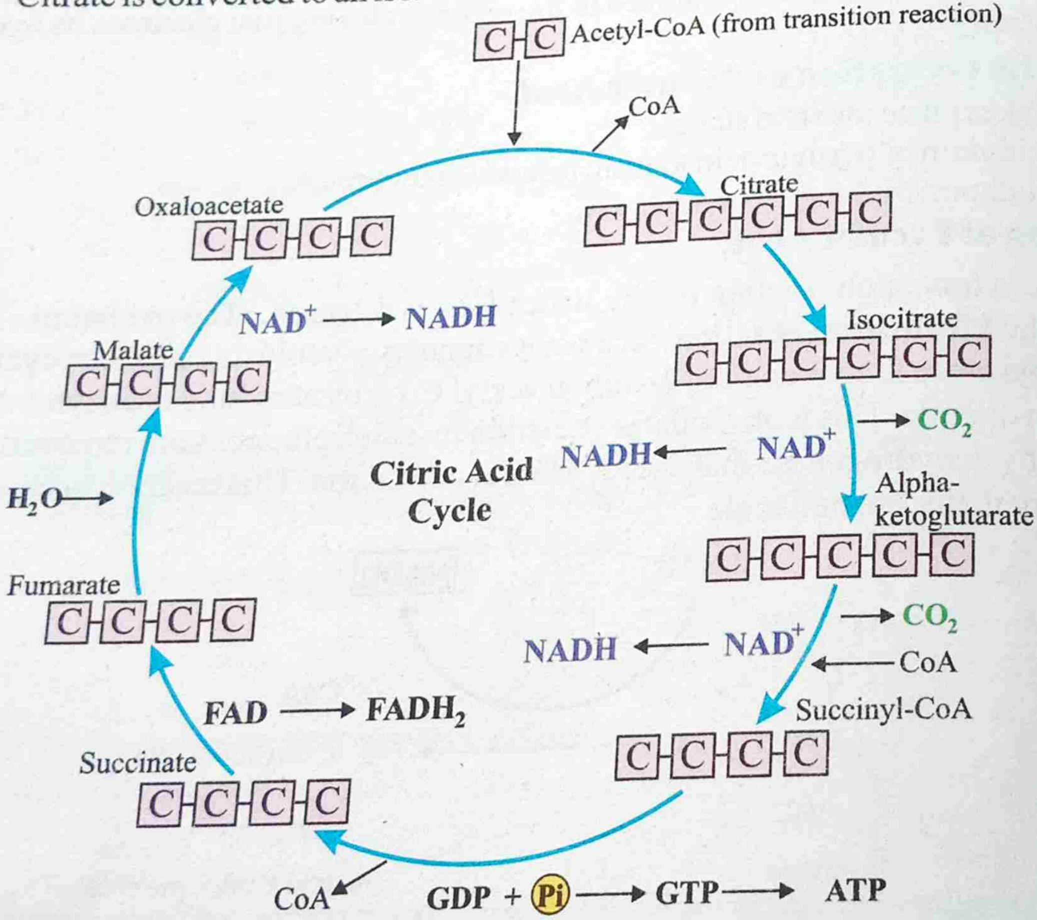


Fig. 4.11 Krebs cycle

Input	Output
2 acetyl groups	$4CO_2$
2ADP + 2Pi	2ATP
6NAD	6 $NADH_2$
2FAD	2$FADH_2$

3. Isocitrate is oxidized by NAD to 5-C alpha-ketoglutarate, NAD is reduced into $NADH_2$ and CO_2 is released.
4. Alpha-ketoglutarate is converted into 4-carbon succinyl CoA and NAD is reduced to $NADH_2$, another molecule of carbon dioxide is removed.
5. 4-carbon Succinyl CoA is oxidized to 4-C molecule, Succinate. GTP is formed which reacts with ADP to form ATP.
6. Now Succinate is converted to 4-carbon Fumarate and FAD is reduced into $FADH_2$.
7. Fumarate combines with water to produce 4 -carbon Malate.
8. Malate is oxidized by NAD to Oxaloacetate and $NADH_2$ is formed.
9. Oxaloacetate is again ready to combine with Acetyl CoA to start a new citric acid cycle.

4.2.5 Electron Transport Chain (ETC)

The ETC is located in cristae of mitochondria. It consists of series of carriers that pass electrons from one to the other. The electrons that enter the ETC are carried by NADH and $FADH_2$ formed during krebs cycle and glycolysis.

Whenever hydrogen is removed from a substrate there are seven intermediate hydrogen acceptors to catch the atom. They are NADH reductase complex (FMN and Fe-S), FADH reductase or co-enzyme Q or Ubiquinone (UQ) and four cytochromes that is b, c, a and a_3 (cytochromes become pink in color when they are reduced. They are protein plus pigment molecules containing iron. They have ability to gain or lose electron. While ubiquinone is not protein it is lipid soluble and water insoluble). Electrons are passed to ubiquinone, at this step an electron is split off the hydrogen atom. The proton becomes free and electron is passed successively from coenzyme Q to cytochrome b, c, a and a_3.

Do you know?

In krebs cycle the extracted electrons are temporarily housed within NADH and $FADH_2$ molecules. These enter in electron transport system where H^+ are removed, ATP and H_2O are formed.

Thinking Questions

Each NADH + H^+ gives 3 ATP in electron transport chain, while each $FADH_2$ gives 2ATP. Can you guess why?

Steps of Electron Transport Chain:

1. The substances in the chain event are alternately oxidized and reduced.
2. Oxidation is accomplished by the loss of hydrogen in case of NAD, FAD and the coenzyme while oxidation is accomplished by loss of electrons from cytochrome b, c, a and a_3.
3. Since two hydrogen atoms are released at a time and cytochrome b through a_3 can accept only one electron at a time so there are two cytochrome systems to capture

the electrons.

4. An electron and proton are brought together after the final transfer from cytochrome a_3. It produces hydrogen.

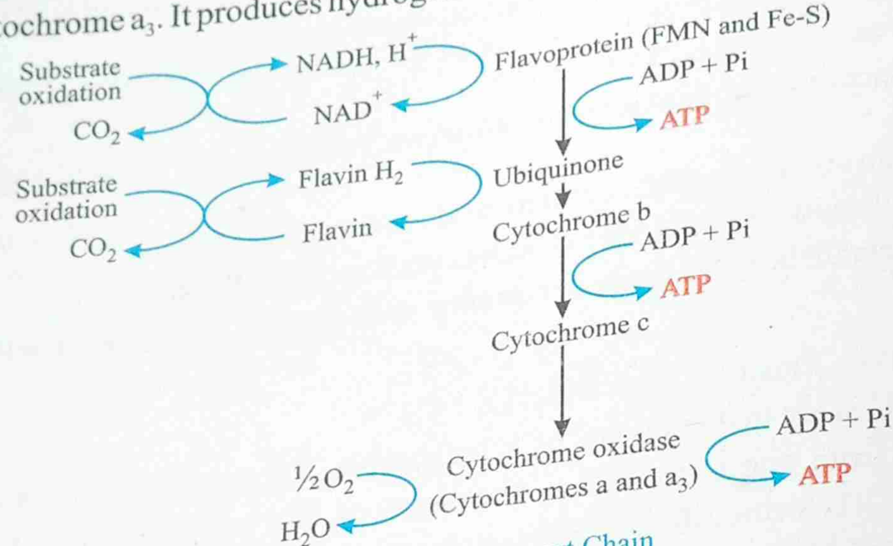


Fig. 4.12 Electron Transport Chain

5. Molecular oxygen is the hydrogen acceptor and water is the final product.

$$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$$

6. Energy is released at three steps, flavoprotein to ubiquinone cyt. b to c, a to a_3. The released energy is captured by ADP to form ATP.

7. Electron transport chain is the main producer of ATP.

4.2.6 Chemiosmosis

Chemiosmosis is the synthesis of ATP from ADP and Pi in the electron transport chain through the joint event of chemical and osmotic processes. The chemiosmotic theory was proposed by Peter Mitchell who got Nobel prize in 1978 for his chemiosmotic theory of ATP production in mitochondria and chloroplasts.

The chemiosmosis can also be defined as the coupling reaction in which synthesis of ATP molecule occurs during the movement of H^+ across a proton gradient. Chemiosmosis generates more ATP as compared to substrate level ATP phosphorylation.

> **Tit bits**
>
> *Chemiosmosis is the movement of ions across a semipermeable membrane, down their electrochemical gradient. For example, generation of ATP by the movement of H^+ across a membrane during cellular respiration or photosynthesis.*

Mechanism of Chemiosmsis:

1. The mitochordrial membranes have transmembrane channels. These channels can pump protons. The flow of electron induce a change in the shape of protein, thus

proton move out of the inner compartment of mitochondria. As a result the proton (H^+ conc.) in the outer compartment of the mitochondrion becomes greater than that of inner compartment.

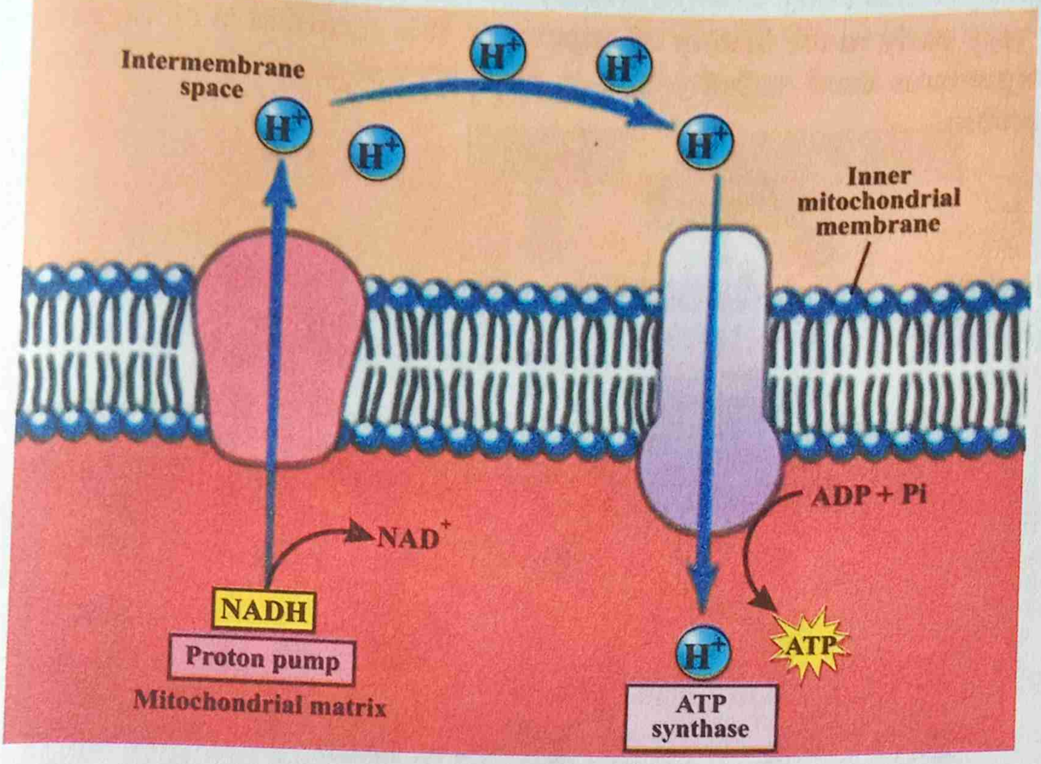


Fig. 4.13 Chemiosmosis

2. Electrical-chemical proton gradient is established between outer and inner membrane. This gradient drives the outer proton across the membrane. Thus the proton move down this gradient between the inner and outer mitochondrial compartments. Their movement induce the formation of ATP from ADP and inorganic phosphate. This process is controlled by an enzyme ATP synthase.
3. The electrons are obtained from the chemical bonds of food molecules in all organisms. This electron removing process needs free oxygen, so it is called aerobic respiration.

Activity

1. Make a list of differences between photosynthesis, respiration and photorespiration.
2. Draw different steps of ETC.

4.2.7 Substrate level phosphorylation

Substrate level phosphorylation occurs in the cytoplasm of the cell during glycolysis and in mitochondrion during the krebs cycle under both aerobic and anaerobic conditions.

ATP formation from ADP and Pi needs input of energy. The energy comes from breakdown of organic molecules in the cells. This type of reaction which releases energy

is called **exergonic reaction.** An enzyme transfers a phosphate group to ADP from a substrate, so ATP molecule is formed. The energy from exergonic reaction is greater than the energy input necessary to drive ATP synthesis. The substrate level phosphorylation appeared very early in the history of organisms. It is recorded in all organisms because initially organisms used carbohydrate as an energy source. Moreover first organisms were anaerobic.

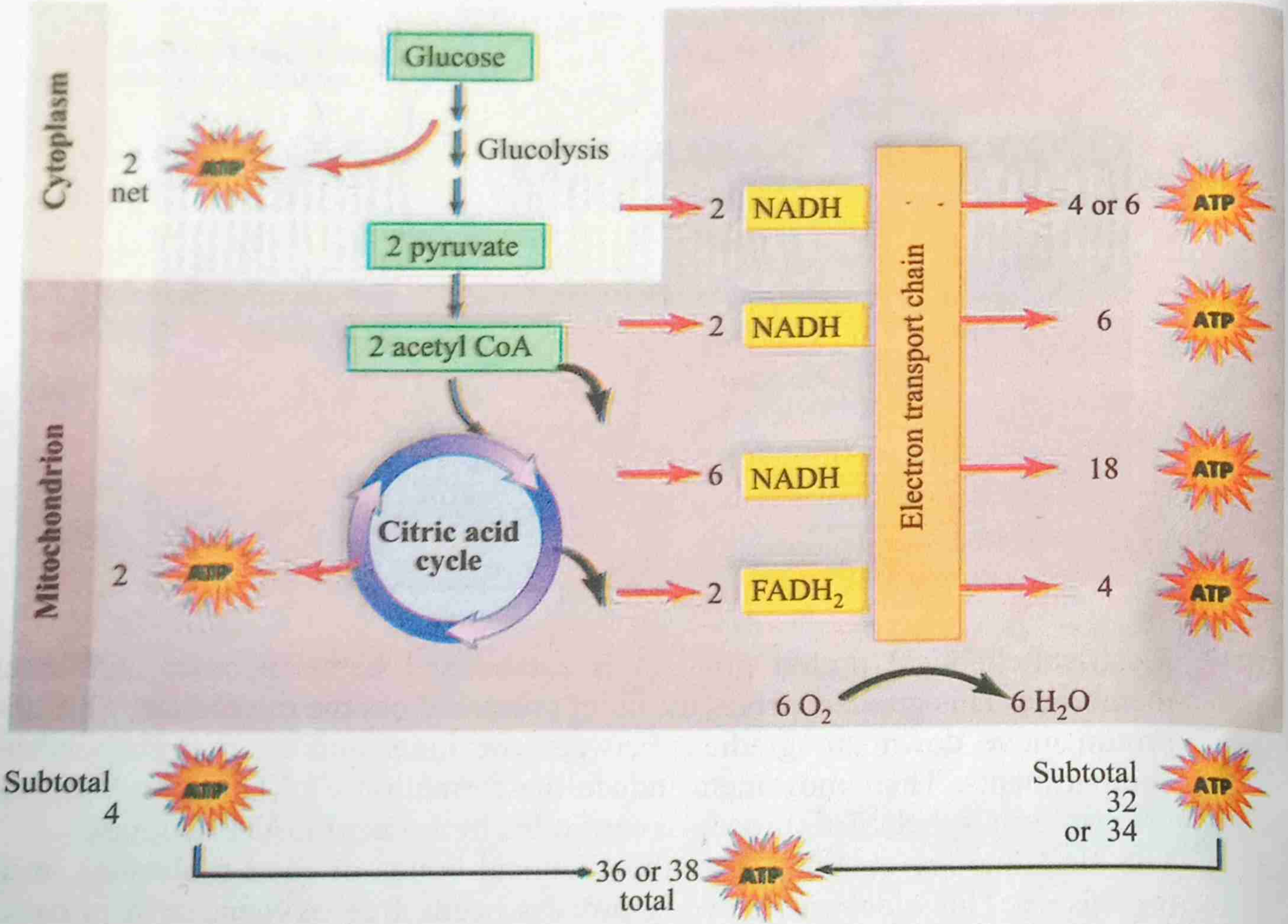


Fig. 4.14 Energy yield per glucose molecule

4.2.8 Importance of PGAL

The preparatory phase of glycolysis completes with the splitting of fructose bi-phosphate into PGAL and Dihydroxyacetone phosphate (DHAP) and both are inter-convertible.

The oxidation of glyceraldehydes 3-phosphate produces 1,3 biphosphoglycerate and 2 NADH molecules which lead to the formation of pyruvic acid.

PGAL is also formed during the Calvin cycle of photosynthesis, one PGAL molecule leaves Calvin cycle. It is converted into glucose phosphate within chloroplast which is converted into starch.

Fixed carbons leave the chloroplast in the form of dihydroxyacetone phosphate. It is formed from PGAL. The DHAP can be used to make the six carbon sugars, glucose and fructose which become a disaccharide, called sucrose. Now sucrose is transported to other parts of the plants.

4.2.9 Cellular Respiration of Proteins and Fats

Animals and humans besides glucose also consume fats and proteins to harvest energy. Fats are broken down into glycerol and three fatty acids. First the glycerol is phosphorylated then enters the glycolytic pathway at the level of glyceraldehyde 3-Phosphate (PGAL) while fatty acids $(2\text{-}C)_n$ enter in the mitochondrion where their carbons are removed. They form acetyl CoA (2-C) which is entry point for krebs cycle (an 18-carbon fatty acid results in nine acetyl CoA molecules). One gram fat provides about 2.5 times more energy than carbohydrates or proteins.

Animals digest proteins into amino acids, if it is in excessive quantity or body is starved then amino acids can be used as fuel. The size of R-group determines whether the carbon chain is oxidizing in glycolysis (Pyruvate) or in the Krebs cycle or .cetyl CoA.

Amino acids are degraded, the amine group is removed to yield ammonia this process is called deamination reaction.

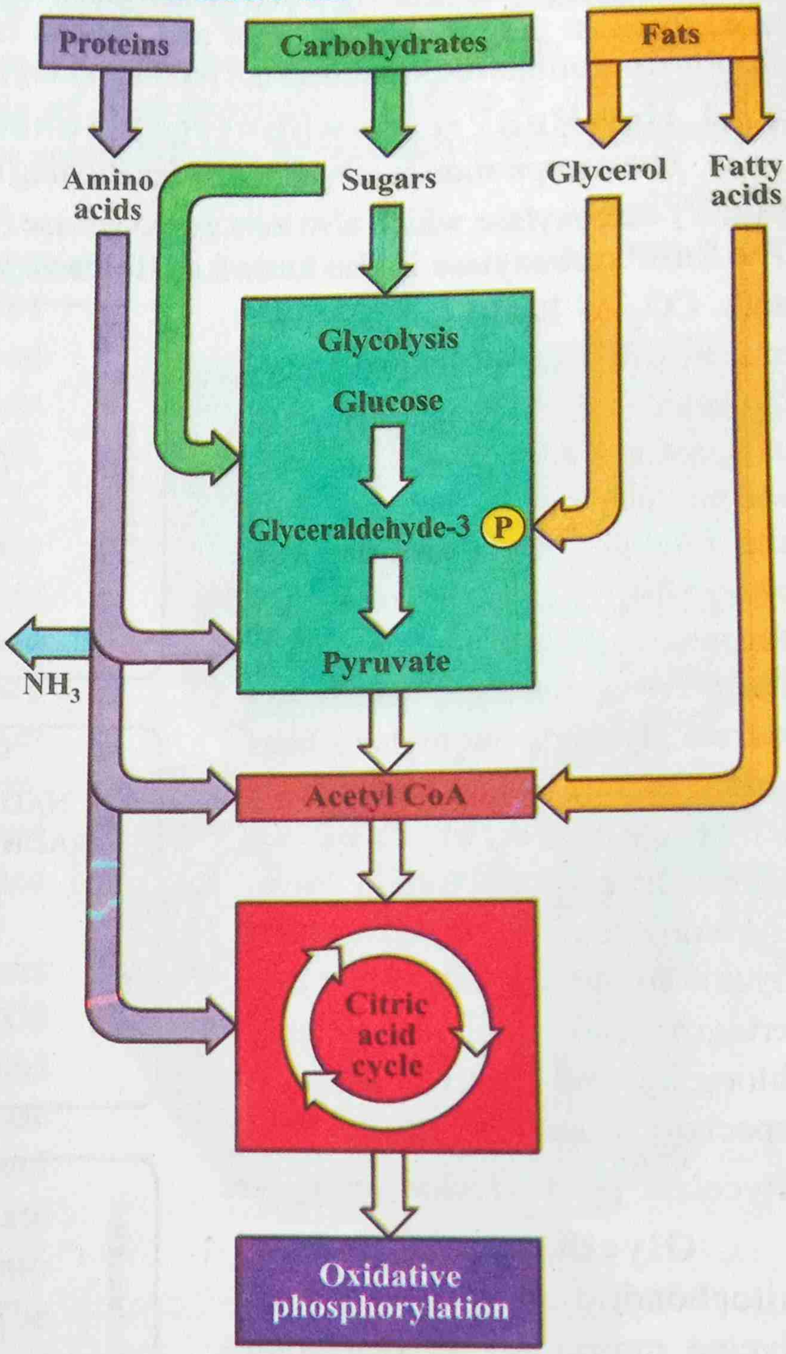


Fig. 4.15 Cellular Respiration of Proteins and Fats

4.3 Photorespiration

This process occurs only in photosynthesizing cells of the plants. It is opposite to photosynthesis, because in it oxygen is used instead of CO_2 and instead of oxygen, carbon dioxide is released (like respiration). It differs from ordinary respiration of cell which occurs in mitochondria at night and in non-green tissues of plant while photorespiration takes place in the presence of light and only in photosynthetic cell. The oxygen is absorbed but unlike respiration do not produce energy (ATP).

4.3.1 How RuBP reacts with oxygen in photorespiration?

Photorespiration is related to the functioning of the enzyme ribulose biphosphate (RuBP) carboxylase which also acts as oxygenase (combines with O_2 instead of CO_2). The RuBP carboxylase is also known as **Rubisco**. When rubisco acts as carboxylase it adds CO_2 to RuBP (an acceptor molecule) to produce two molecules of PGA while during oxygenase, it adds oxygen to RuBP and produces one molecule of PGA and one phosphoglycolate. The phosphoglycolate loses its phosphate to become glycolate. There are some algae which can excrete glycolate but higher plants cannot excrete it. Therefore, plants must convert it back to intermediate in the Calvin cycle. The conversion of glycolate into glycine amino acid takes place by a series of reactions in mitochondria, chloroplast and other cellular parts especially in peroxisomes.

Glycolate $\longrightarrow$ glycine amino acid

Glycine diffuses into mitochondria where every two glycine molecules are converted into serine amino acid and CO_2.

2 glycine $\longrightarrow$ Serine + CO_2

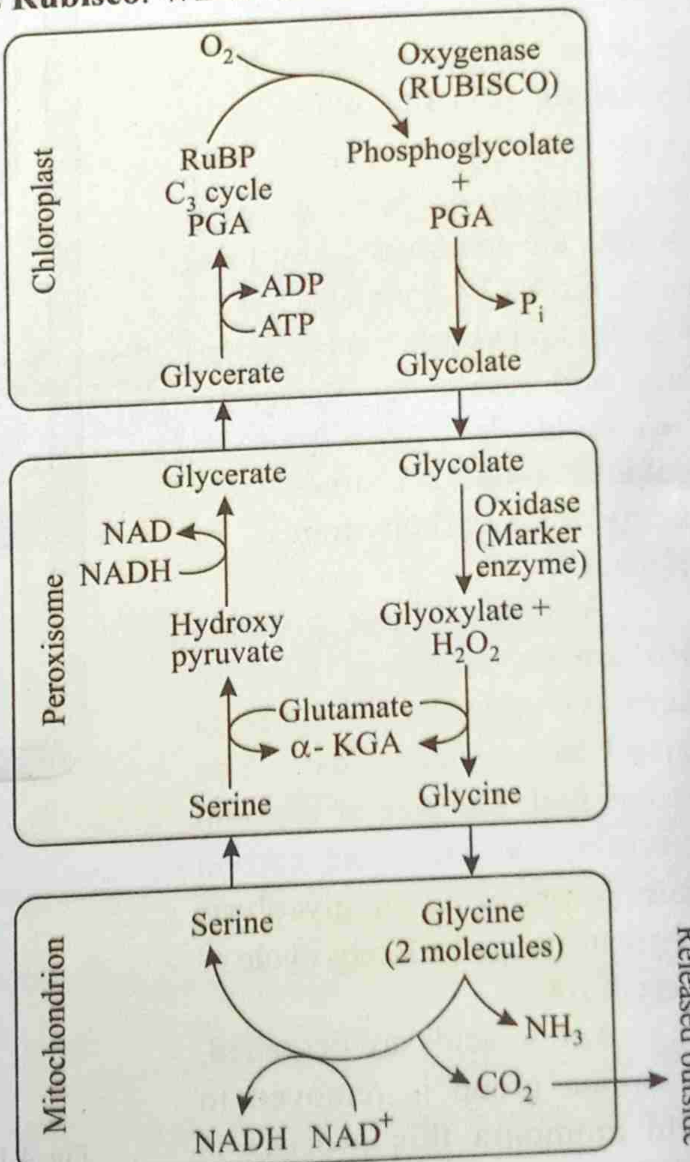


Fig. 4.16 Photorespiration

This entire pathway is called photorespiration in which RuBP is converted into serine and CO_2 which uses ATP and $NADPH_2$ produced during light reaction like Calvin cycle.

4.3.2 Disadvantages of photorespiration

It is reverse to Calvin cycle (here CO_2 is released instead of being fixed into carbohydrates). Photorespiration reduces the amount of carbon fixation into carbohydrates by 25%. The role of photorespiration in plants is not thoroughly understood. It is presumed that photorespiration may be necessary for the assimilation of nitrates from the soil.

4.3.3 Photosynthesis in C4 plants

In normal process of photosynthesis a 3-C compound called PGA is formed as a first detectable product of photosynthesis. Therefore, these plants are called C_3 plants. However, there are some plants growing in dry and hot conditions which produce a four carbon compound (C4) called oxaloacetate as the first product of photosynthesis in dark reaction. These plants are called C4 plants and this type of photosynthesis is called C4 photosynthesis.

C3 plants use rubisco to react CO_2 with RuBP, on the other hand C4 plants use a different enzyme called phosphoenol pyruvate carboxylase **(PEPCO)** to fix CO_2 to a compound known as phosphoenol pyruvate (PEP). The PEP is reduced into another molecule called malate. The malate carry CO_2 to a special type of cells called bundle sheath cells where Calvin cycle proceeds.

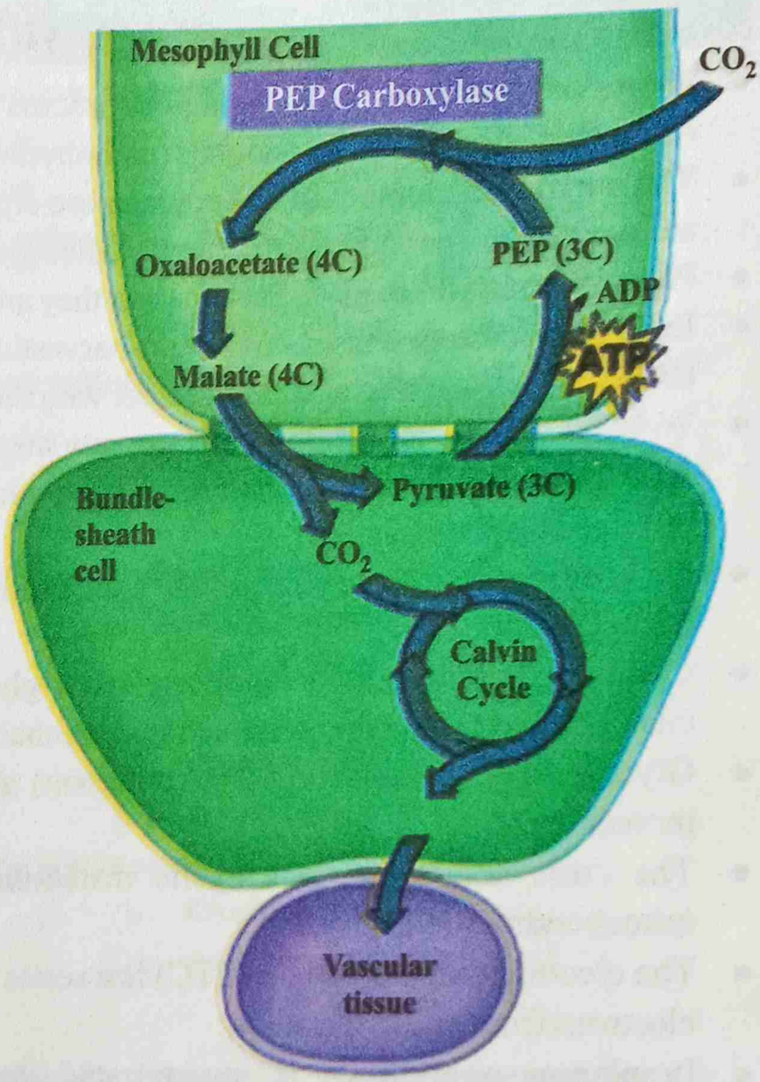


Fig. 4.17 C4 pathway

Table 4.2 Comparison between C_3 and C_4 Plants

C_3 Plants	C_4 Plants
In C_3 chloroplasts are located only in mesophyll cells of leaf.	In C_4 chloroplasts are present both in mesophyll cells as well as in bundle sheath cells.
In these plants all the mesophyll cells carry out Calvin cycle.	In these plants only mesophyll cells fix CO_2 by using PEPCO while the bundle sheath cells carry out Calvin cycle.
In high temperature photosynthesis is low.	In high temperature the rate of photosynthesis is high.
Example: Most of the plants are C_3 plants such as pea, wheat, rice and all woody trees.	*Example:* They are found only in angiosperms such as sugar cane, maize and mostly grasses.

SUMMARY

- Photosynthesis is the only biological process that captures energy of sunlight and converts it into organic compounds (carbohydrates).
- The internal membranes of chloroplasts are organized into sac-like thylakoids which are stacked on one another in columns called grana.
- Photosynthesis takes place in two steps: they are light reaction and dark reaction.
- Each photosystem consists of a light-harvesting complex and a core complex. Each core complex contains a reaction center with the pigment (either P700 or P680).
- To build organic molecules, cells use raw materials provided by the light reactions. ATP provided by cyclic and noncyclic photophosphorylation while $NADPH_2$ provided by photosystem I.
- Cellular respiration is the process in which cells acquire energy by breaking down the organic compounds.
- Cellular respiration involves four phases: glycolysis, the preparatory reaction, the citric acid cycle, and the electron transport chain.
- Glycolysis is the breakdown of (6-carbon) glucose into two (3-carbon) pyruvate molecules.
- The citric acid cycle is a cyclic metabolic pathway located in the matrix of mitochondria.
- The electron transport chain (ETC) is a series of

EXERCISE

Section 1: Objective Questions

Multiple Choice Questions

A. **Choose the best correct answer from the following.**

1. Which among the following conditions is favourable for cyclic photo-phosphorylation:
   (a) Aerobic
   (b) Aerobic and low light intensity
   (c) Aerobic and optimum light
   (d) Anaerobic and low light intensity
2. During the dark reaction of photosynthesis:
   (a) Water is split off
   (b) CO_2 is reduced to organic compounds
   (c) Chlorophyll is activated
   (d) Glucose is broken down
3. The enzyme that fixes atmospheric CO_2 in C4 plants is:
   (a) PEP carboxylase (b) Rubisco
   (c) RuBP carboxylase (d) Hydrogenase
4. The number of carbon atoms in RuBP which accepts CO_2 are in C3 plants is:
   (a) 2 (b) 3
   (c) 5 (d) 6
5. Chlorophyll *a* differs from chlorophyll *b* in having a:
   (a) -CHO group (b) -COOH group
   (c) $-CH_3$ group (d) $-NH_2$ group
6. NADP is:
   (a) An enzyme (b) A part of rRNA
   (c) A coenzyme (d) A part of tRNA
7. The compound that enters the Krebs cycle from glycolysis is:
   (a) Citric acid (b) Oxaloacetate
   (c) Pyruvic acid (d) Acetyl coenzyme A

B. **Fill in the blanks.**

1. Breakdown of water molecule during PS II of light reaction is called______.

Introduction

The life form which exists without a cellular structure is known as **acellular** or non-cellular life. The primary candidates for non-cellular life are viruses. Majority of biologists consider viruses are non living because they are not capable of **autopoiesis** (ability of reproduction) without host. The other examples of acellular life are **viroids** which are smallest infectious agents consisting solely of short strands of circular single stranded RNA without protein coat. The **prions** are infectious agents composed entirely of protein, capable of multiplying itself and transferable from one host to another.

5.1 Viruses Discovery and Structure

A virus is a biological agent that reproduces only inside the cells of living host. Viruses can infect all type of life forms i.e., from animals and plants to microorganisms including bacteria.

In 1884 the French microbiologist **Charles Chamberland** made a filter paper for filtration of bacteria. In 1892, Russian biologist **Ivanovsky** used this filter to determine the cause of **tobacco mosaic disease.** In his experiment he proved that tobacco mosaic disease was not caused by bacteria but caused by other infectious agent which can pass through filter paper. He called these filterable viruses. His view was confirmed by American virologist **W.M. Stanley in 1935,** when he observed tobacco mosaic virus under Electron Microscope.

In the early 20th century (1915, 1917) **Twort and Herelle** discovered bacteriophages (viruses that infect bacteria). Since then thousands of species of viruses have been discovered and microbiologists speculate that there are millions of species of viruses still to be discovered.

5.1.1 Viruses Living or Non Living

Viruses show the characteristics of both living and non-living things. The **living characteristics** of viruses include:

- They have their own genetic material.
- They undergo mutation.
- Can reproduce inside host cell by using host metabolic machinery.
- Get destroyed by ultraviolet radiations and chemicals.
- Occur in different varieties or strains.

The **non-living characteristics** of viruses include:

- They are non-cellular particles.
- Generally lack enzymes and co-enzymes and depend upon host enzymes and coenzymes for their metabolic activities.
- Can be crystallized and stored in laboratory.
- Do not respire and use the energy of host for their activities.
- Therefore, depending upon the ambivalent(fluctuating) nature of characteristics possessed by the Viruses; they are considered on **boundary line between living and non living things.**

5.1.2 Classification of Viruses

Viruses may be classified on the basis of morphology, type of host they infect, presence or absence of outer covering and types of nucleic acid.

Classification of viruses based upon structure (morphology):

1. On the basis of capsid:

- Some viruses have helical capsid such as tobacco mosaic virus (TMV).
- Many have polyhedral capsid, contain a glycoprotein spike at each vertex, such as adenovirus.
- Viruses possess an outer envelope studded with glycoprotein spike, such as Influenza viruses.
- Viruses like bacteriophage possess complex capsid consisting of a polyhedral head and tail apparatus.

2. On the basis of genome (DNA and RNA):

- Double stranded DNA viruses (dsDNA Viruses). e.g., Adenoviruses, Herpes viruses, Pox viruses.
- Single stranded DNA viruses (ssDNA Viruses), e.g., Paroviruses (small viruses of vertebrates and invertebrates) cause rash.
- Double stranded RNA viruses (dsRNA viruses), e.g., Reoviruses, cause diarrhoea.
- Single stranded RNA reverse transcribing viruses template for DNA (ssRNA-RT viruses), e.g., HIV (retrovirus).

> **Do you know?**
>
> *Bacteriophages are ubiquitous viruses found wherever bacteria exist. It is estimated that number of Bacteriophages is more than any other organism on earth.*

Classification of viruses on the basis of host they infect:

- **Bacterophages** attack bacteria.
- **Plant viruses** which cause more than 2,000 types of plant diseases such as TMV, Potato yellow dwarf virus.
- **Animals viruses** cause many diseases to animals and human such as mouth and foot disease in livestock, papovavirus causes mumps and measles. Rous sarcoma virus causes cancer.

5.1.3 Structure of Model Viruses

A virus particle (virion) consists of nucleic acid core surrounded by a protective coat of protein called capsid. The nucleic acid found in viruses is either DNA or RNA but

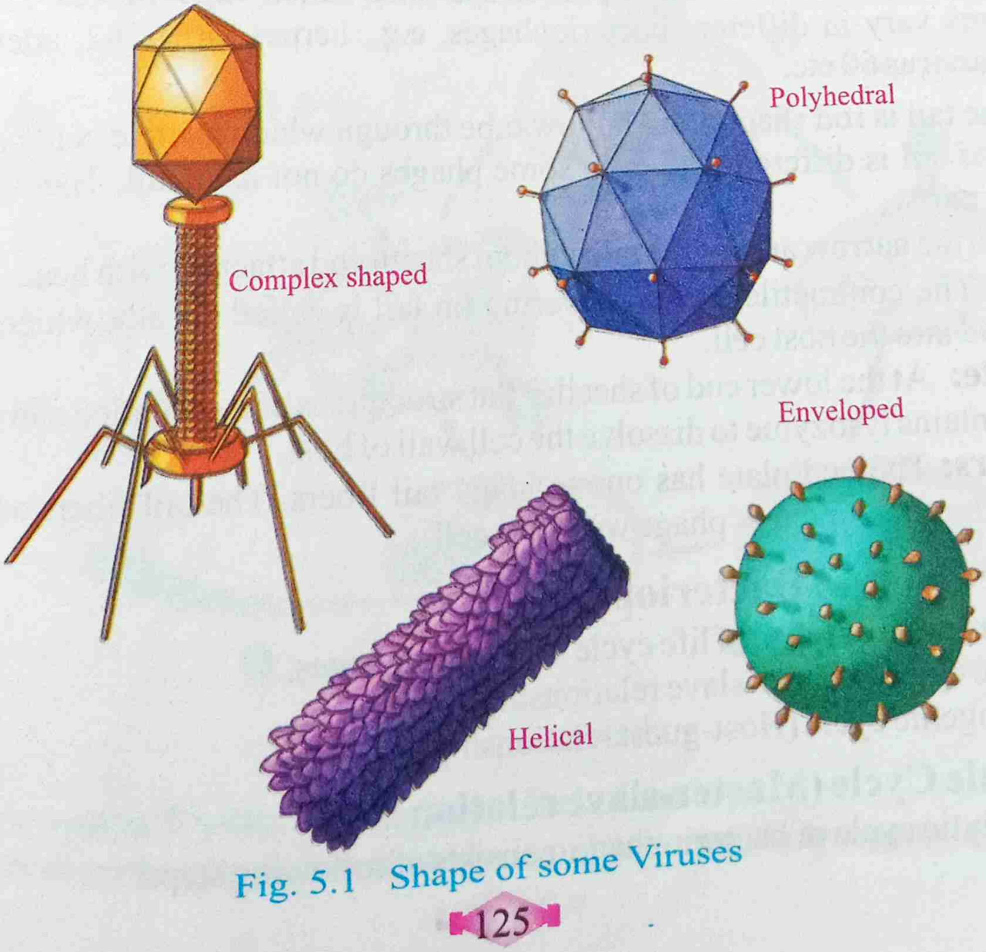


Fig. 5.1 Shape of some Viruses

not both. The **capsid** is made of many smaller, identical protein molecules called **capsomeres.** Their number and arrangement varies in different types of viruses. Some viruses have an **envelope** of lipid outside the protein coat. This envelope is derived from host cell and such viruses which have envelope are called enveloped viruses. The viruses have different shapes like enveloped, tadpole or complex shaped, polyhedral, spherical, helical etc.

Structure and life cycle of some viruses (Bacteriophages, flu virus and HIV):

5.1.4 Structure of Bacteriophage

A Bacteriophage is a virus that infects and replicates within a bacterium. They vary in size from 24 to 200 nm in length. A bacteriophage consists of two main parts, i.e., head and tail.

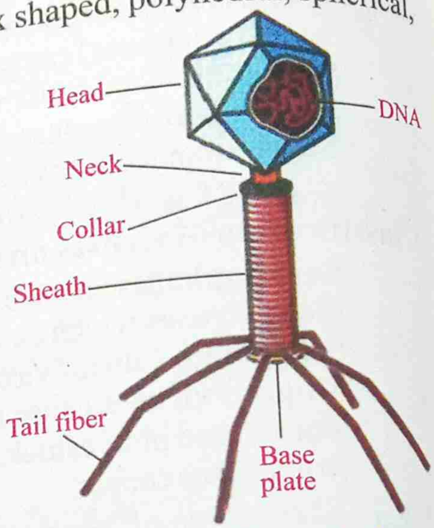


Fig. 5.2 Bacteriophage

Head: The head (nucleocapsid) is further divided into two parts, inner core of nucleic acid and outer coat of protein. The nucleic acid may be mostly DNA, however, some have RNA . The number of genes in a bacteriophage genome vary from few to over 100.

The protein coat or capsid of bacteriophage is usually **hexagonal** like prism shaped. The capsid is made up of protein sub units called **capsomeres**. The number of capsomeres vary in different bacteriophages, e.g., herpes virus 162, adenovirus 252, ambidensovirus 60 etc.

Tail: The tail is rod shaped and hollow tube through which nucleic acid passes in host. The size of tail is different and even some phages do not have tail. The tail consists of following parts.

Neck: It is the narrow area of the tail without sheath and attached with head.

Sheath: The contractile protein covering on tail is called sheath, which pushes the nucleic acid into the host cell.

Base Plate: At the lower end of sheath a flat structure is present called end plate or basal plate. It contains lysozyme to dissolve the cell wall of host.

Tail Fibers: The end plate has one to many tail fibers. The tail fibers and base plate involve in the attachment of phage with host cell.

5.2 Life Cycle of Bacteriophage

There are two types of life cycle of bacteriophages.

i) Lytic cycle (Master-slave relationship)

ii) Lysogenic cycle (Host-guest relationship)

5.2.1 Lytic Cycle (Master-slave relationship)

The lytic cycle of bacteriophage consists of following steps.

antibiotic re... strains. ...to degrade the bacterial ...as alternative to antibiotics for many

5.2.3 Influenza or Flu Virus

It is an RNA enveloped virus, belongs to family orthomyxoviruses. It includes seven genera but out of seven three genera usually cause influenza in humans and some other vertebrates. These three genera are influenza virus A, influenza virus B and influenza virus C. Each genus include only one species, i.e., influenza A, B and C virus.

The **influenza** A and C cause infection in different vertebrates including humans but **influenza** B almost exclusively infects human.

Vaccines and drugs are available for the treatment of influenza virus infection but flu viruses develop resistance against these vaccines and drugs. Therefore, vaccines and drugs have to be reformulated regularly.

Do you know?

The total genome length of flue virus is 12000-15000 nucleotides and the genome contains 6-8 segments or pieces of varying lengths.

Symptoms of influenza

include fever, shivering, dry cough, chill, loss of appetite, body-ache, nausea, irritation in throat and nose etc.

Human Immunodeficiency Virus (HIV):

Human immunodeficiency virus (HIV) is an RNA enveloped virus. It is spherical in shape. It is a retrovirus, i.e., it can convert its RNA into DNA in host cell. It causes aquired immunodeficiency syndrome (AIDS) in humans. It belongs to family retroviridae and genus lentivirus.

Structure of HIV:

It is roughly spherical in shape, about 120 nm in diameter. HIV consists of two strands of RNA enclosed by a conical capsid. The capsid is surrounded by an envelope.

The envelope is formed when the capsid buds off from host cell, taking some of the host cell membrane with it. The envelope contains glycoprotein receptors responsible for binding to and entering the host cell. Several enzymes like reverse transcriptase, protease and integrase are also present.

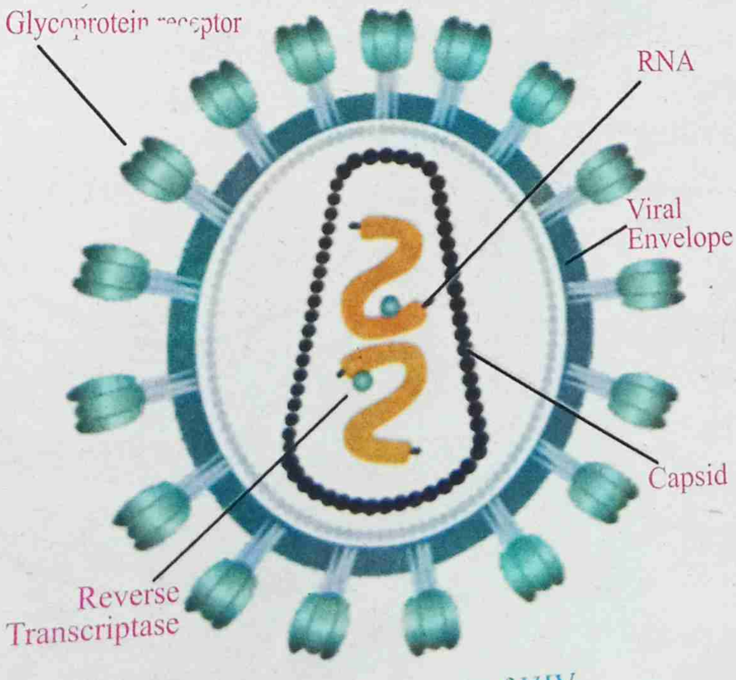


Fig. 5.5 Structure of HIV

5.3 Discovery of HIV

HIV causes AIDS (Acquired immunodeficiency syndrome). The HIV was first identified in 1984 in France and USA. The name HIV (Human immune deficiency virus) was given to this virus in 1986. HIV attacks on some special type of white blood cells (macrophages, lymphocytes). These cells are known as T4 cells and are the primary hosts of HIV.

5.3.1 Life cycle of HIV (How does HIV recognize T4 cells?)

The HIV has glycoprotein receptors on its envelope while T4 cells have CD4(Cluster of differentiation) receptor, during travelling in blood HIV glycoprotein receptors stick with T4 cells on CD4 protein receptors.

> **Tit bits**
>
> *HIV screening test is done by ELISA. However, ELISA test is relatively less authentic, so PCR test is recomended which is more authentic.*

Once HIV binds to a host cell, the viral envelope fuses with the cell membrane, the RNA and enzymes of virus enter into the host cell. Three types of enzymes of HIV which come into host cell along with RNA are reverse transcriptase, integrase and protease. The reverse transcriptase converts viral RNA into DNA. The enzyme **integrase** then facilitates the delivery of this viral DNA into the host DNA.

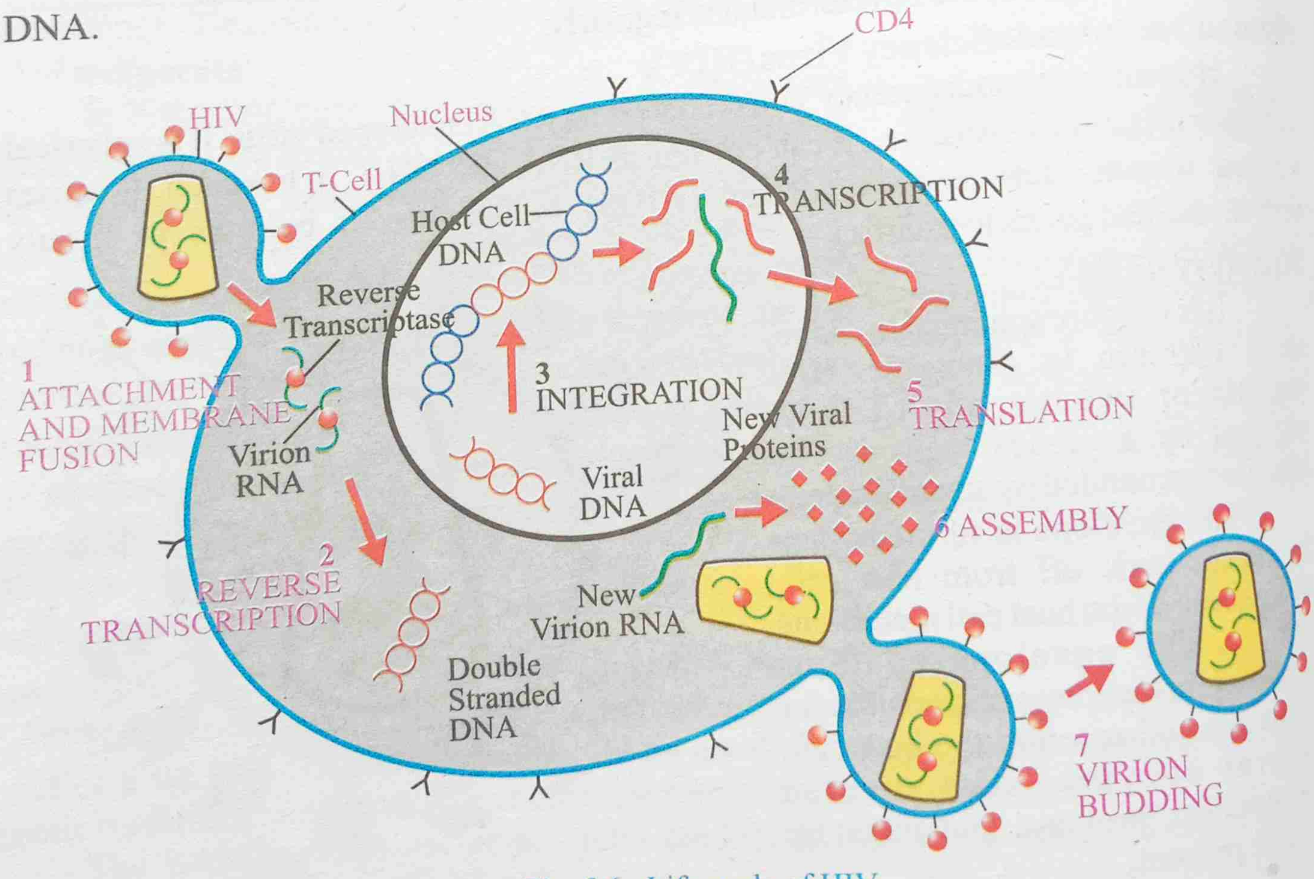


Fig. 5.6 Life cycle of HIV

The integrated DNA is now called provirus. Virus mRNA is transcribted in host cell by host cell polymerase. This mRNA is translated into proteins. These proteins are large in size which are then cleaved by the protease enzyme to form virion structural proteins. Thus immature virion is produced which is budded off from cell membrane. As it buds off, it takes the covering of host cell membrane and becomes mature infectious virion. A cell infected with retrovirus does not necessarily lyse the cell when its replication takes place. In HIV infection T4 cells are destroyed thus immunity is decreased and patient becomes susceptible to other diseases. As it causes immune system deficiency so it was called HIV (Human Immunodeficiency virus).

Tit bits

There are two species of HIV, i.e., HIV-I and HIV-II. HIV-I is most common pathogenic strain while HIV-II is not widely recognized outside Africa.

Symptoms of AIDS:

The infection of HIV may be divided into three stages. **The first** stage is known as primary infection. In this stage symptoms like fever, swollen lymph nodes, inflammation of throat, night sweating occur. However, these symptoms disappear after some days and there are no symptoms for about nine months, therefore, this first stage is called **asymptomatic carrier.**

The second stage known as **AIDS related complex**. In this stage some of early symptoms of acute infection reappear like swollen lymph nodes under the armpit, neck region, groin region, fever, aches etc. Some other symptoms like persistent cough, persistent diarrhoea, flu, night sweating, loss of memory, loss of judgment and depression, weakness etc. This stage may continue from few months to many years.

The last stage of HIV infection is called **full blown AIDS.** This stage is characterized by severe weight loss, weakness and opportunistic infections such as **kaposi's sarcoma** (skin cancer), **cervical cancer** and **cancer of lymphatic** system. Opportunistic infections are such infections which are caused by very weak pathogens which usually never cause infection as our immune system can easily destroy them.

Red Ribbon

The red ribbon is a symbol for solidarity with AIDS patients.

Transmission of AIDS:

The HIV is transmitted by three main routes i.e., sexual contact, body fluids and mother to child.

The sexual contact is most frequent cause of HIV transmission. The second most common mode of HIV transmission is **body fluid,** it includes blood transfusion, surgical instruments, contaminated syringes, razors, blades etc. **The mother to child** transmission may occur during pregnancy, during delivery or breast feeding.

World AIDS Day

1st December is world AIDS Day, it is being observed every year since 1988. It is dedicated to raising awareness about AIDS prevention.

Prevention of AIDS:

There is currently no cure or vaccine to prevent or cure HIV infection. A treatment

known as **highly active antiretroviral therapy** (HAART) is given but no significant improvement is observed. Therefore, prevention is the only cure for AIDS. The following **preventive measures** are recommended to avoid HIV infection.

i) Avoid immoral sexual contacts and follow Islamic teachings in order to live clean and healthy life.
ii) Surgical instruments must be sterilized before use.
iii) Disposable syringes should be used. Blood must be screened before transfusion.
iv) Do not share razor blades and tooth brushes.
v) HIV positive mothers should avoid breast feeding.

5.4 Parasitic Nature of Viruses

Viruses are obligate parasites i.e., they cannot reproduce and live outside living cells. It is because viruses lack metabolic enzymes, ribosomes, mitochondria etc for making protein and energy. Therefore, viruses must need a host cell for their life cycle.

Viruses are highly specific with respect to their hosts, e.g., HIV attacks on T4 cells of human. Polio virus infects spinal nerve cells. Hepatitis virus attacks on liver cells. Bacteriophages attack only bacteria etc. However, some viruses have a broad range of specificity e.g., rabies virus can infect all mammalian cells.

When any foreign agent enters inside the body it is destroyed or killed by macrophages and neutrophils or antibodies produced by Bursa lymphocytes. But in some capsule, protein and fibrin do not bind by geg (swing) like substances secreted by Bursa lymphocytes which are used by macrophages and neutrophils. That is why viruses are saved from being phagocytized. Some viruses cover with host proteins, therefore, body immune system is unable to detect them as foreign body and they remain protected. Many viruses continuously change their shape and appearance as a result body immune system and vaccine becomes ineffective against new types, e.g., influenza and HIV viruses also remain safe in the body when immune system gets weak as in AIDS.

How viruses tolerate unfavorable conditions outside host cell?

Outside the host cell viruses are changed into crystals. In crystal form they are seen dead and show no activities. Upon reaching the host cell, i.e., in favorable condition they become active again and start reproducing by using host enzymes and proteins. The crystals of viruses may be present in saliva, respiratory droplets, feces etc.

5.5 Viral Diseases

A disease caused by virus is known as viral disease. Viruses cause number of diseases in plants, animals and human beings. A brief introduction of some viral diseases is given below.

Hepatitis:

Hepatitis is the inflammation of liver (Gk. *Hepa* = Liver, *itis* = inflammation).

There are different causes of hepatitis such as alcohol, drugs and toxins. However, hepatitis is mostly caused by viral infections. There are several types of viral hepatitis like A, B, C, D and E.

Hepatitis A: It is caused by RNA virus called HAV. The HAV is non-enveloped icosahedral shaped virus which cause a mild, short term disease. It is transmitted by contact with feces from infected person and drinking sewage contaminated water.

Vaccine is available for the prevention of HAV but no antiviral therapy is available.

Hepatitis B: Serum Hepatitis: It is caused by DNA enveloped virus called HBV. It is transmitted by blood, sexual contact, contaminated blood transfusion and by infected mothers to their babies, saliva etc. It may cause liver cirrhosis and death if not treated timely. The vaccine for HBV is available. **Alpha interferon** and some nucleoside analogues are effective treatment for HBV.

Hepatitis C: It is caused by RNA enveloped virus called HCV. It is a chronic and fatal disease, may cause cirrhosis, hepatocellular carcinoma and death if left untreated. The mode of transmission is via blood, sexual contact, breast feeding, sharing needles, tooth brushes etc. No vaccine is available for HCV, however, antiviral therapy is available usually a combination of interferon and ribavirin is given to the patients.

Hepatitis D: It is caused by HDV also called delta virus. This virus is only active in the presence of HBV, so it can be treated or prevented by treating HBV. Its mode of transmission is also same as HBV. It is small spherical enveloped viroid.

Hepatitis E: It is caused by HEV. It is non-enveloped single stranded RNA virus. The symptoms of HEV are similar to HAV. But it can be more fulminant in some cases such as pregnancy. No vaccine or antiviral drugs available.

Herpes: There are two types of herpes viruses which cause herpes, i.e, herpes simplex virus I and II. These are double stranded DNA viruses having large genome covered with protein coat and envelope. Herpes simplex-I is known as cold sore while herpes simplex-II is known as genital herpes. Herpes-I is transmitted by saliva while herpes-II is transmitted by sexual contact. The symptoms include water blisters in the skin or mucous membranes of mouth, lips, nose, genitals and skin lesions. Herpes can be treated by using antiviral drugs and may be prevented by avoiding sexual contacts and physical contacts with infected persons.

Tit bits

Polio virus is usually spread by infected fecal matter entering the mouth. It may also spread by food and water contaminated by feces or saliva.

Tit bits

Polio has been almost eradicated from world. However, Pakistan, Afghanistan and Nigeria are the countries where polio cases are identified.

Poliomyelitis (infantile paralysis)

It is highly infectious viral disease that can lead to paralysis, breathing problem or even death. This virus was first identified by Karl Landsteiner in 1908. Primarily, it is

transmitted by contaminated water of infected fecal material but may also be transmitted by sneezing and coughing. There are many different symptoms of polio. These symptoms may be divided in two types.

i) Non-paralytic polio symptoms: These include flu, weakness, fever, sore throat, headaches, vomiting, fatigue, muscle tenderness etc.

ii) Paralytic polio symptoms: These include loss of muscle reflexes, severe muscle pain spasm and damage to motor nerve etc.

There is no cure for polio, however, it can be prevented by vaccination. Two types of polio vaccines are available, i.e., inactivated polio vaccine (IPV) and oral polio vaccine (OPV).

Tit bits

Prions have different structure than normal protein of body. Therefore, they are resistant to protease enzyme.

Leaf Curl Virus Disease

Leaf curl is a plant disease characterized by curling of leaves, darken veins and veins swellings. The disease mainly affects the cotton plant which is one of the most important crop of Pakistan, accounting for over 60% of foreign exchange earnings.

In Pakistan this disease was first reported in Punjab region near the city of Multan in 1985. Now it is spread in other parts of Pakistan and the neighbouring countries. It is a main threat to cotton crop. It is caused by a cotton leaf germinivirus (CLCuV). The vector of this virus is whitefly *Bemisia tabaci*. Therefore, this disease can be prevented by protecting the cotton seedlings from the attack of whiteflies. The infected plants should be burnt and healthy seeds should be used for sowing.

Fig. 5.7 Cotton Leaf Curl Disease

Bird Flu in Pakistan

Bird flu is also called avian influenza. It is a viral infection that can infect not only birds but also humans and other animals. However, most forms of virus are restricted to birds.

H_5N_1 is the most common form of bird flu. It is deadly disease of birds and it can also easily affect humans and other animals that come in contact with infected birds. H_5N_1 are capable to survive for long

Fig. 5.8 Birds infected from birds flu virus

to prevent

Activity

Relate enzyme activity with antibiotics by searching internet and find out the reason why antibiotics are not effective against viruses.

5.6 Prions

Prions are proteinaceous infectious particles which cause transmissible neurodegenerative disease. Stanely in 1982 discovered these particles. The prions affect the nervous system of human and other mammals.

The transmission of prion is mainly by unhygienic way of feeding, contaminated food. Some prions diseases of human are **creutzfeld Jacob disease (CJD), kuru, fatal familial insomnia (FFI).** These diseases are caused by eating beef products obtained from cattle with prions diseases. **Scrapie** is a common disease of bovine caused by prion. It is also known as **mad cow disease**. Loss of memory, paralysis, destruction of nerve tissues are symptoms of prion disease. No effective treatment is available and illness is progressive and always fatal.

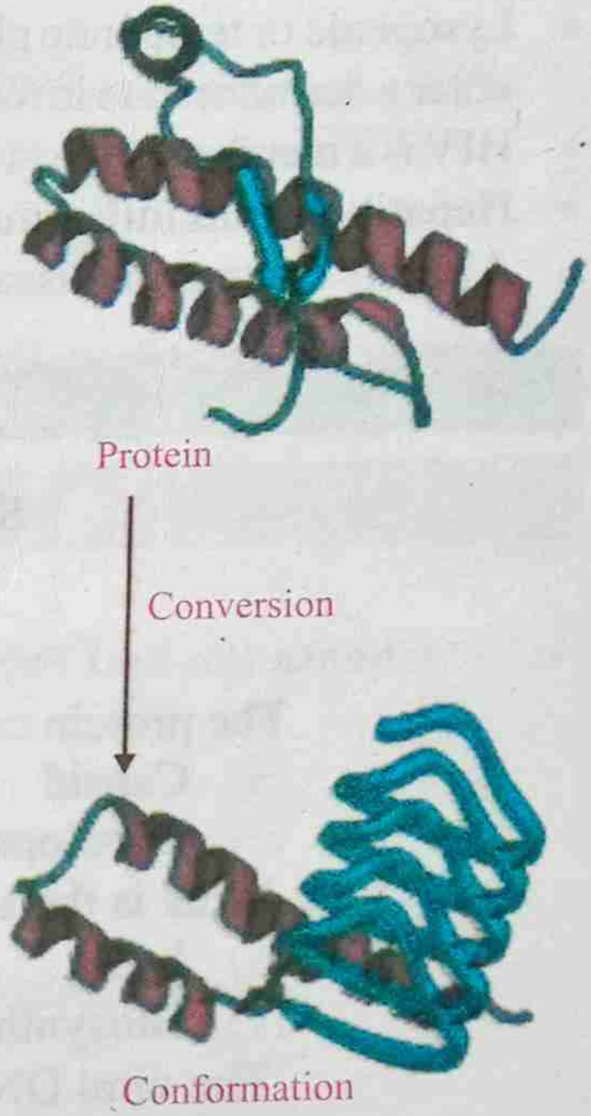


Fig. 5.9 Structure of Prion

Viroids

Viroids are single molecules of circular RNA without a protein coat or envelope so they are called simple RNA. These are smaller in size than virus, ranging from 246-270 nucleotides.

Viroid was first discovered by T. O. Diener in 1971. Viroids cause diseases in plants such as **potato spindle tuber** disease, **cucumber pale fruit.**

The mechanism of viroids replication is unclear so far.

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

Choose the best correct answer.

1. The protein coat of a virus is called the:
   (a) Capsid (b) Capsomere
   (c) Envelope (d) Viral membrane
2. What is the second step of bacteriophage infection
   (a) Lysis (b) Attachment
   (c) Biosynthesis (d) Penetration
3. The viral DNA incorporated into a lysogenic cycle is called.
   (a) Prophage (b) Latent phage
   (c) Bacteriophage (d) Oncogenic virus
4. Prions cause disease by
   (a) Altering normal proteins (b) Altering genes
   (c) Activity of a reverse transcriptase (d) Produce poison

5. What type of infectious agent causes potato spindle tuber disease?
(a) Prion
(b) Virino
(c) Viroid
(d) Virus

6. Prion diseases can be acquired in all of the following ways except by
(a) Transplantation
(b) Inherited
(c) Direct contact
(d) Ingestion

7. Carbohydrate-protein complexes that project from the surface of some viruses are
(a) Caspid
(b) Capsomeres
(c) Envelope
(d) Spikes

B. **Fill in the blanks.**

1. Prions are infectious particles which are composed of only________.
2. Viroids consist of only a single molecule of circular________without protein coat.
3. Polio virus is transmited by the________.
4. Master-slave relationship of bacteriophage is called________cycle.
5. Host-guest relationship of bacteriophage is called________cycle.
6. The tail of phage secretes an enzyme named________.
7. HEV is non enveloped single stranded________virus.

Section II: Short Questions.

Write short answers.

1. What is meant by an obligate intracellular parasite?
2. What is the capsid?
3. What is an enveloped virus, and how does the envelope arise?
4. Write short note on prion.
5. Define bacteriophages and explain their structure.
6. What is necessary for adsorption?
7. What is a prophage or temperate phage?
8. What is the principal effect of the agent of Creutzfeldt-Jakob disease?
9. What are viroids?
10. Why the viral diseases are more difficult to treat than bacterial diseases?

Section III: Extensive Questions.

Introduction

A **prokaryote** (Gk. *Pro* = before, *Karyons* = nucleus) is a unicellular organism having simple structure that lacks a membrane-bound nucleus and other membrane-bound organelles like mitochondria, Golgi complex etc. Prokaryotes have great economic and environmental importance. They also greatly affect on human health and largely used in research and biotechnology.

6.1 Taxonomy of Prokaryotes

The A. V. Leeuwenhoek (Dutch scientist) first discovered bacteria in 1674 and called them **animalcules**. Ehrenberg introduced the name **bacterium** in 1828 (Gk: bacterion means small staff or rod). The taxonomic position of bacteria and other prokaryotes have witnessed continuous changes since their discovery.

6.1.1 Taxonomic position of Prokaryotes as kingdom(Monera)

According to two kingdom system of classification all microorganisms were included in kingdom **Plantae.** In 1861 **John Hog** proposed a separate kingdom **Protista** for all microorganisms including **bacteria.** In 1866 **Ernst Haeckel** made a separate group the **Monera** for Prokaryotes within same kingdom Protista. In 1938 **Herbert Copeland** separated group Monera from Protista and formed the **kingdom Monera** in which he had placed only prokaryotic organisms. **Robert H. Whittaker** an American biologist in 1969 proposed five kingdom system of classification for living things. **Lynn Margulis** and **Karlene Shwartz** in 1988 modified five kingdom classification. They distinguished between kingdoms according to cellular organization and mode of nutrition. They had placed all prokaryotes in kingdom monera, whereas eukaryotes were classified into four kingdoms *viz.* Protista, Plantae, Fungi and Animalia.

6.1.2 Taxonomic position of prokaryotes as "Domain Bacteria" and "Domain Archaea"

Earlier the term bacteria was used for all microscopic unicellular prokaryotes but later molecular systematics studies exhibit that prokaryotic life consists of two separate **domains**. Thus, both these domains have superceded the kingdom as a broadest taxonomic group. Bacteria and Archaea evolved independently from an ancient common ancestor. These two domains, along with Eukarya, are the basis of the three domain system, which is currently the most widely used classification system in bacteriology.

6.1.3 Phylogenic position of prokaryotes

Phylogeny is the evolutionary relationship among various groups of organisms (e.g., Species or populations). The study of phylogenic evolutionary history of a species or group of related species is called **systematics**. The bacterial phylogeny was reconstructed in 1977. The new phylogenetic taxonomy is based on the discovery of genes encoding ribosomal RNA because there is little or no change in ribosomal RNA generation after generation. **Thus ribosomal RNA are commonly recommended as**

molecular clock for reconstructing phylogenies. Now prokaryotes are divided into two evolutionary domains as part of the three domain system, **Archaea Eubacteria** and **Eukaryotes.** The genes sequence studies indicate that bacteria diverged first from the archaeal/ eukaryotic lineage.

Most scientists hold view that bacteria and archaea probably evolved from **hyperthermophile** that lived about 2.5 to 3.2 billion years ago.

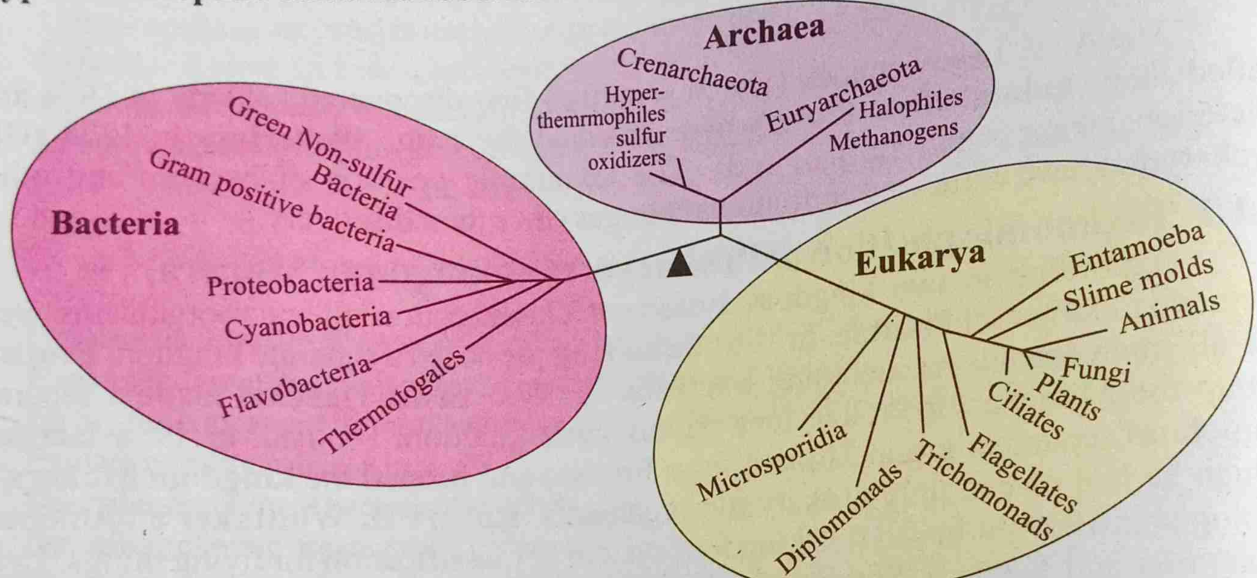


Fig. 6.1 Phylogenic Position of Prokaryotes

6.2 Archaea

The microorganisms belong to domain archaea are unicellular prokaryotes, previously known as **archaeobacteria**. Archaea exhibit similarities both with bacteria as well as eukaryotes.

They also differ from bacteria and possess unifying features thus placed in separate domain. The **unifying archaeal features** are:

1. Their **plasma membrane** contains different kinds of lipids than bacteria which allows them to function at high temperature.
2. The **cell wall** in bacteria is made up of carbohydrate-protein complex called **peptidoglycan** but the cell wall of archaea lacks this complex. Their cell wall is largely composed of polysaccharides or pure protein.
3. The **rRNA** of archaea is unique, i.e., different from that of bacteria.
4. **Lipid** of bacteria contain glycerol with fatty acids while lipid of archaea contain glycerol linked to branched chain of hydrocarbons.
5. A unique ability of **methanogenic** archaea is formation of methane.
6. Archaea are mostly **autotrophs**.

6.2.1 Habitat of Archaea

Most live in extreme environments. There are three types of archaea:

(i) Methanogenic archaea (ii) Halophiles

(iii) Thermoacidophilies.

The **methane** (Biogas) producing archaea are known as **methanogen,** which inhabit anaerobic environments like marshes, swamps, digestive tract of animals and human. These archaea produce biogas (methane) from hydrogen gas and CO_2 coupled to the formation of ATP (example of methanogen is *Methanobacterium formicom*).

The **halophiles**, inhabit salty environment where other organisms can not live such as salty meat, example of halophiles is *Halobacterium halobium*.

The **thermoacidophiles** inhabit extreme hot and acidic environments. Their example is *Pyrolobus fumarii,* recorded in hot springs, geysers, volcanoes etc.

6.3 Bacteria Ecology and Diversity

Bacteria have a wide range of habitat. They exhibit diversity in their size, shape and mode of nutrition.

6.3.1 Occurrence

Bacteria are found everywhere in this planet where life exists such as body of living and dead organisms, water, soil, milk, skin, humid forests etc.

6.3.2 Major Groups of Bacteria

Dr. Hans Christian Gram (1884) has divided bacteria into two major groups by using staining technique, i.e. **Gram positive and Gram negative.** His grouping depends upon chemical makeup, permeability, metabolism, presence of endospores, physiological characteristics, growth and nutrition in bacteria.

Table 6.1 Comparison between Archaea and Bacteria

Basis of comparison	Archaea	Bacteria
Habitat	Unusual environment like hot springs, ocean depth, salt brine.	Everywhere like soil, water, living and non living organisms.
Cell wall	Psuedopeptidoglycan, largely composed of polysaccharide or pure protein.	Peptidoglycan with muramic acid or lipopolysaccharide.
Membrane	Branched carbon chain.	Unbranched carbon chain.
Types	Methanogen, Halophiles, Thermoacidophiles	Gram positive and Gram nagetive.
Other features	No thymine in tRNA. Introns are present. Non-pathogens RNA polymerase is complex similar to eukaryotic, mostly autotrophic but no photosynthesis.	Thymine in the tRNA. Introns are absent. Some are pathogens. RNA polymerase simple and small, photosynthesis present but mostly heterotrophic.
Examples	*Sulfolobus acidocaldarius, Pyrococcus furiosus.*	*Streptococcus pneumonia, E.coli.*

6.4 Structure, Shape and Size of Bacteria

A typical bacterium consists of cell wall, cell membrane, nuclear region, cytoplasm and also other structures outside cell wall.

> **Tit bits**
>
> *Peptidoglycan is also called murein. It has long chains of sugars with short chains of amino acids (normally 4-5 amino acids).*

6.4.1 Structure and Chemical Composition of Bacterial Cell Wall

All bacteria possess cell wall except Mycoplasma. The cell wall protects the cell and also gives it a definite shape. It is made up of **peptidoglycan** (sugar-protein complex found in Prokaryotes) and is rigid.

6.4.2 The cell wall of Gram positive and Gram negative bacteria

Based on the variations in the chemical components of cell wall, Danish physician, **Hans Christian Gram**, developed a staining technique in 1884 and divided bacteria into two groups i.e., Gram positive and Gram negative bacteria.

Gram Positive: These bacteria are stained blue purple with crystal violet dye. They have thick wall of peptidoglycan. They retain dye when the cells are washed with an organic solvent like alcohol.

Gram negative: These bacteria have thinner layer of peptidoglycan. They lose the dye easily when rinsed with alcohol and stain pink. The thin peptidoglycan layer is externally covered with a layer of lipopolysaccharides, lipoproteins and phospholipid. Thus they are more resistant than gram-positive against antibiotics (lipopolysaccharide impedes the entry of antibiotics).

> **Tit bits**
>
> *In many bacteria cell membrane invaginates into cytoplasm to form folds called mesosome which helps in cell division and replication of DNA.*

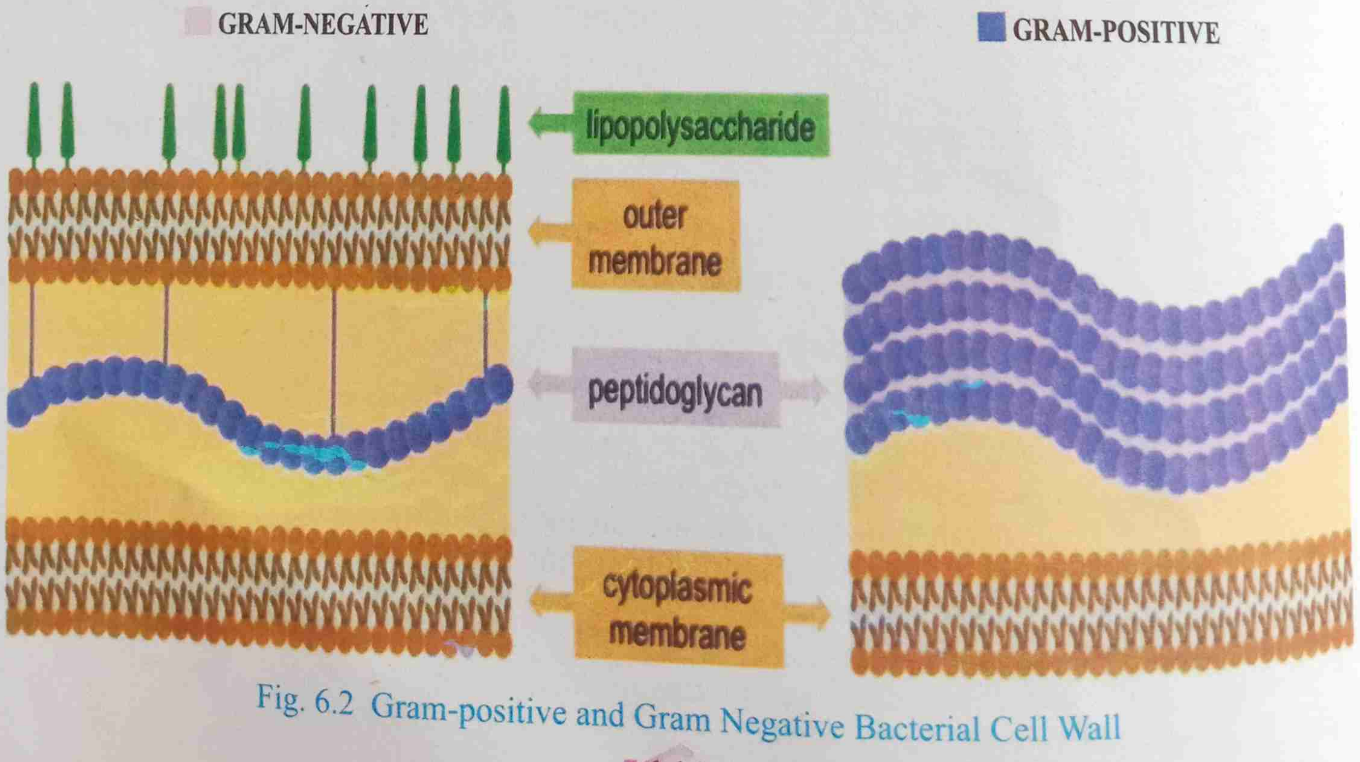


Fig. 6.2 Gram-positive and Gram Negative Bacterial Cell Wall

Table. 6.2. Differences between Gram-positive and Gram negative cell wall

Character	Gram Positive	Gram Neagative
Thickness	20 to 80 nm	8 to 10 nm
No. of Layers	One	Two
Porins proteins	Absent in all	Present in all
Peptidoglycan	More	Less
Lipid	Less	More
Outer membrane	Absent in all	Present in all
Chemical composition	Peptidoglycan, Teichoic acid, Lipoteichoic acids	Lipopolysaccharide, Lipoproteins and Peptidoglycan

Slimy Capsule:

Some bacteria contain additional protective outer envelope, secreted by the cell known as slimy capsule. It is made of polysaccharide which helps in defence and adhering to host tissues. The encapsulated bacteria cause disease while the same bacteria without capsule do not cause disease, e.g., *Diplococus pneumoniae* causes pneumonia.

6.4.3 Shape and Size of bacteria

There are three main shapes of bacteria; Spherical, Straight and Spiral shape.

Spherical or Cocci (Singular Coccus): Cocci are spherical in shape. They are non-motile because they lack flagella, may be single or colonial. The colonial may be diplococci (group of two cells) tetrad (group of four cells), octet (packet of eight cells), Streptococci (long chain of cells), Staphylococci (bunch of cells like grapes). Examples of Cocci are *Streptococcus pneumoniae, Neisseria meningitidis* etc.

Straight Shape or Bacilli (Singular Bacillus): Bacilli are straight or rod shaped bacteria. They posses flagella and are motile. Most of them occur either singly or colonial. They are found in pairs (diplobacillus), very short and oval shaped (coccobacilli), curved and coma shaped (Vibrio), stack (Pallisade). Examples of bacilli are *Bacillus subtilis, Escherichia coli* etc.

Spiral Shaped or Spirochetes: These are corkscrew shaped bacteria, flexible, motile and flagellated. They usually occur singly and seldom form colonies e.g., *Helicobacter pylori* and *Treponema pallidum.*

Most bacteria range in size about 0.1 to 600 micrometer over a single dimension.

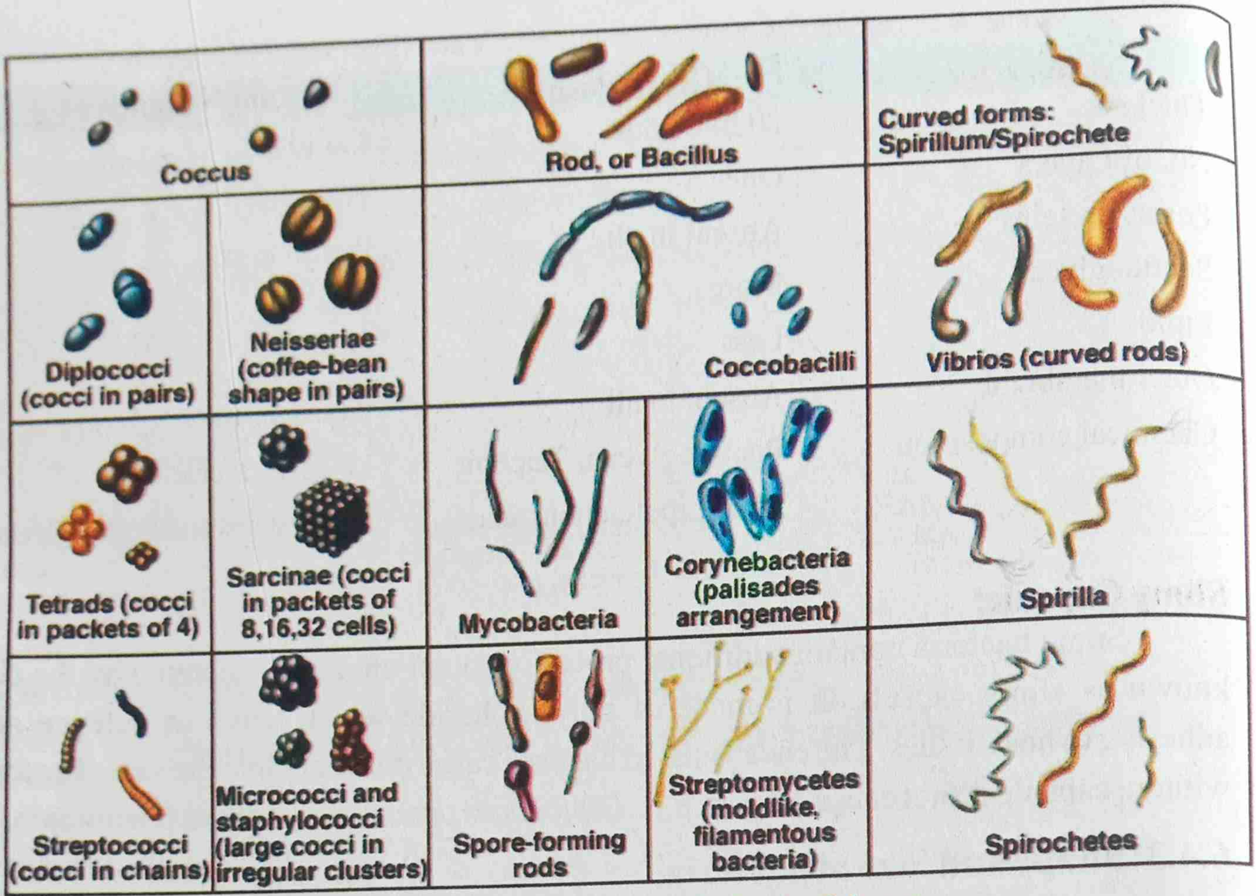


Fig. 6.3 Types of bacteria on the basis of shapes

6.4.4 Endospores

Some Gram-positive bacteria produce highly resistant structure known as endospore which during unfavorable conditions serves for the survival of the bacteria. It develops within vegetative cell, so named endospore. The original cell forms a copy of its chromosome and covers it with hard wall, water is removed and metabolism stops.

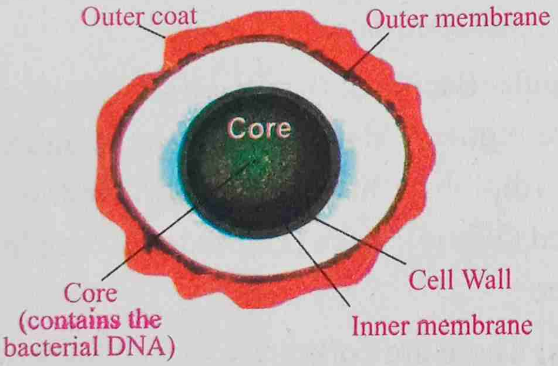


Fig. 6.4 Endospore in Bacteria

> **Do you know?**
>
> *Pili are small hollow appendages mostly present all around the body. Their role is attachment of bacteria to host tissue, mating (conjugation) and chemotaxis.*

Endospores remain dormant but viable for centuries. The parent body disintegrates. At the return of favorable conditions endospores are reactivated to normal form and restart division cycle.

6.4.5 Locomotion in Bacteria

Most bacteria possess flagella as locomotary appendages, which help in gliding, twitching motility or change of buoyancy. The spirochetes have helical body which help them to twist about as they move. During twitching motility pili help in anchoring. Flagella are commonly found in bacilli and spirilla while most cocci are without flagella known as atrichous. There are two types of arrangement of flagella, i.e., polar and peritrichous.

Polar flagella are situated at one end or both ends of bacteria and divided into following types.

Monotrichous: single flagellum at one end, e.g., *vibrio*.

Lophotrichous: a cluster of flagella at one, end e.g., *spirillum*.

Amphitrichous: flagella at both poles.

Amphilophotrichous: tuft of flagella at both ends.

Peritrichous: flagella are arranged all around the body e.g ., *Salmonella typhi*.

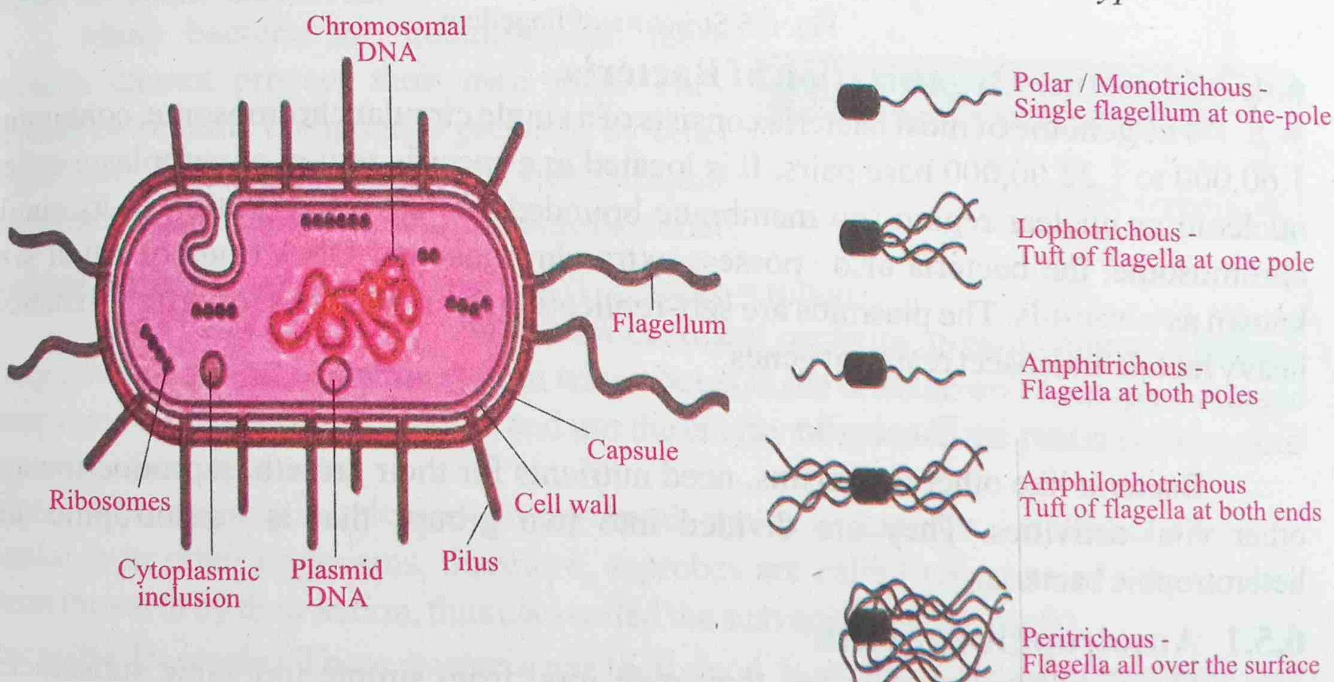


Fig. 6.5 Generalized structure of bacterium and types of flagellar arrangement

6.4.6 Structure of Flagella

A flagellum is made of three parts, i.e., basal body, a short curved hook and a helical filament, consists of several protein chains. Protein of flagella is flagellin.

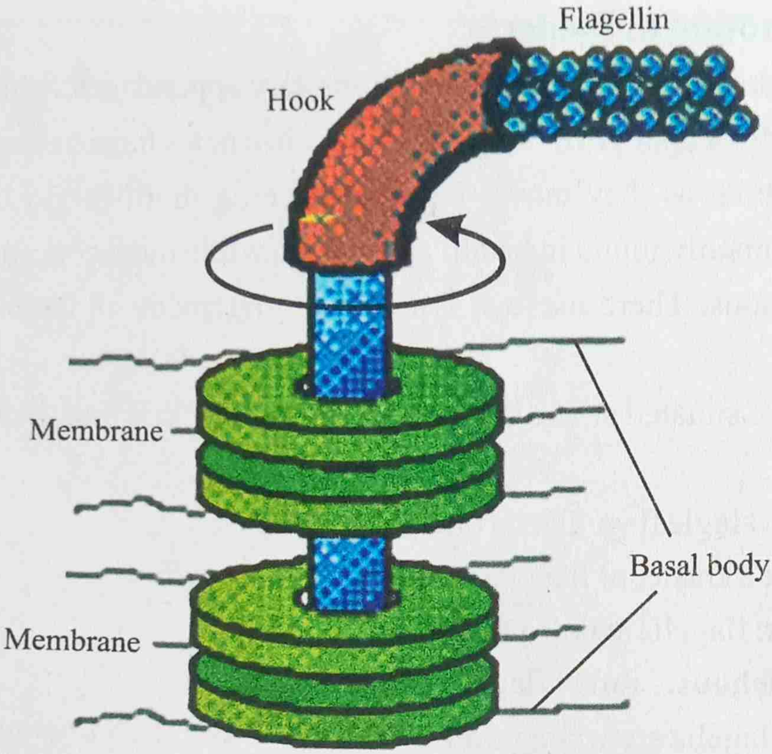


Fig. 6.6 Structure of flagellum

6.4.7 Genomic Organization of Bacteria

The genome of most bacteria consists of a single circular chromosome, containing 1,60,000 to 1,22,00,000 base pairs. It is located in a specific region of cytoplasm called nucleoid or nuclear region (no membrane bounded nucleus). In addition to its single chromosome, the bacteria also possess extra chromosomal DNA rings of small size known as **plasmids**. The plasmids are self-replicating, contain genes for drug resistance, heavy metals and insect resistant genes.

6.5 Nutrition in Bacteria

Bacteria like other organisms, need nutrients for their growth, reproduction and other vital activities. They are divided into two groups that is autotrophic and heterotrophic bacteria.

6.5.1 Autotrophic bacteria

These bacteria synthesize their own food from simple inorganic substances. They obtain all the carbon from inorganic carbon compounds such as carbon dioxide. The autotrophic bacteria are further divided into two groups namely photoautotrophic and chemoautotrophic.

Photoautotrophic or Photosynthetic Bacteria:

These bacteria possess chlorophyll, located either in the membrane of their mesosomes or freely dispersed in cytoplasm. Bacteria have unique type of chlorophyll

that is chlorophyll *e* and *f* are known as **bacteriochlorophylls**. Photoautotrophic bacteria use the energy of sun light, H_2S as "H" source (instead of H_2O) and liberate "S" instead of O_2 to make carbohydrate (organic food) from CO_2.

$$2H_2S + CO_2 \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} \underset{\text{Carbohydrate}}{(CH_2O)_n} + H_2O + 2S$$

Examples of photosynthetic bacteria are purple sulphur bacteria, green sulphur bacteria, purple non-sulphur bacteria.

Chemoautotrophic or Chemosynthetic Bacteria:

These bacteria do not have chlorophyll thus do not use sunlight as source of energy. They derive energy by oxidation of inorganic substances such as H_2S, NH_3, NO_2, NO_3 and iron compounds. The energy of above inorganic substances is used to synthesize carbohydrates.

$$2H_2S + O_2 \xrightarrow{\text{oxidized}} 2S + H_2O + \text{release energy}$$

The energy released is utilized to make carbohydrates.

$$2H_2S + CO_2 + \text{energy from oxidation} \longrightarrow (CH_2O)_n + H_2O + 2S$$

The example of chemosynthetic bacteria are denitrifying bacteria, sulphur bacteria.

Heterotrophic Bacteria:

Many bacteria are heterotrophic, these bacteria cannot prepare their own food. They depend on organic compounds prepared by other organisms. There are two types of heterotrophic bacteria that is saprotrophic and parasitic bacteria.

> **Do you know?**
>
> *Heterotrophs directly or indirectly depend on photosynthetic organisms.*

Saprotrophic Bacteria or Saprobs (Gk. Sapro = rotten)

These bacteria get their food from dead and decaying organic matter (Humus). They have a powerful enzyme system which helps in the breakdown of complex organic compounds into simple substances and use the energy released in the process. Examples: *Pseudomonas, Azobacter.*

(**Note:** The chemicals released during break down of organic substances become available to other organisms, therefore, saprobes are called recyclers of nature. They clean the earth by their action, thus also called the scavengers of the earth).

Parasitic Bacteria: These bacteria get their food from the host and depend on host enzymes to make food. Parasitic bacteria include pathogenic bacteria (disease causing) examples are *Mycobacterium, Streptococcus pneumoniae.*

Respiration in Bacteria:

Respiration in bacteria may be aerobic and anaerobic.

Aerobic bacteria need oxygen to breakdown food, e.g., *Pseudomonas.*

Anaerobic bacteria breakdown food without oxygen, e.g., *Spirochetes.*

Facultative bacteria grow either in the presence or absence of oxygen, e.g., *E.coli.*

Microaerophilic bacteria need a low concentration of oxygen for their growth, e.g., *Campylobacter.*

6.6 Growth and Reproduction in Bacteria

Growth in bacteria means the increase in the total population rather than increase in the size of organism. Their growth is very fast and depend on suitable temperature, availability of nutrients, pH and ionic concentration; If conditions are favorable then most bacteria divide after every 20 minutes, e.g., *E.coli.* The interval between two successive divisions is known as **generation time**. It is different in different species.

6.6.1 The Growth Phases of Bacteria

There are following four phases of growth in bacteria.

Lag phase (no growth): Bacteria prepare themselves for coming division i.e., adapting to its new environment and growth has not yet achieved its maximum rate.

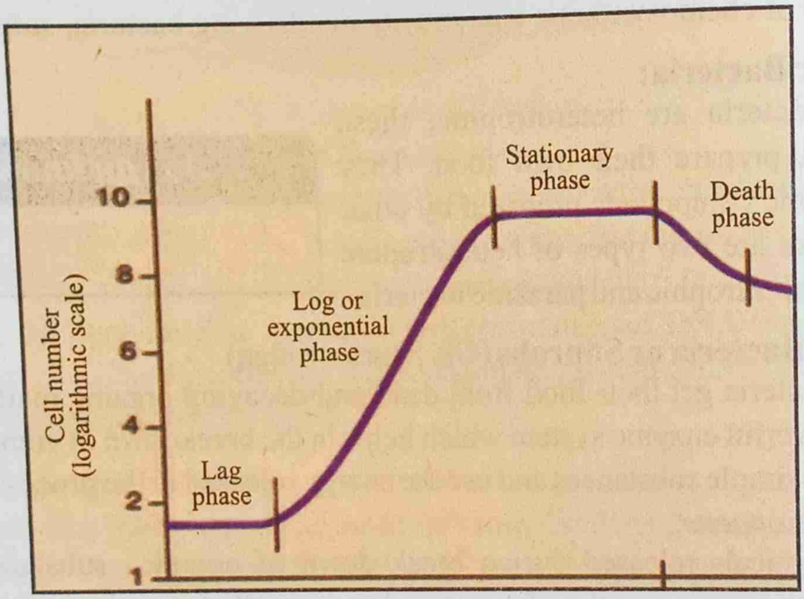


Fig. 6.7 Growth Curve of Bacterial Population

Log phase (rapid growth period): Fast growth occurs at this phase. In human the disease symptoms develop during the log phase because the bacterial production attains such a high level which damage the tissues.

Stationary phase (equal birth and death rate): After log phase, the growth slows down because of shortage of nutrients. Thus rate of reproduction and death of bacteria becomes equal.

Death phase (decline phase): In this phase death rate increases and reproduction rate decreases. It is due to exhaustion of nutrients and accumulation of toxic wastes.

6.6.2 Reproduction in Bacteria

Bacteria reproduce both asexually and sexually.

Asexual Reproduction (Binary fission): All bacteria reproduce asexually by means of **binary fission.** There is a single chromosome, having a circular DNA molecule. First DNA is replicated and attached to the plasma membrane. After duplication the two chromosomes move towards their respective sides. The plasma membrane pushes inward at the center of the cell. The cell wall grows inwards to separate both daughter cells from each other thus two daughter bacteria are formed. In most bacteria, it takes 20 minutes, if conditions are favourable.

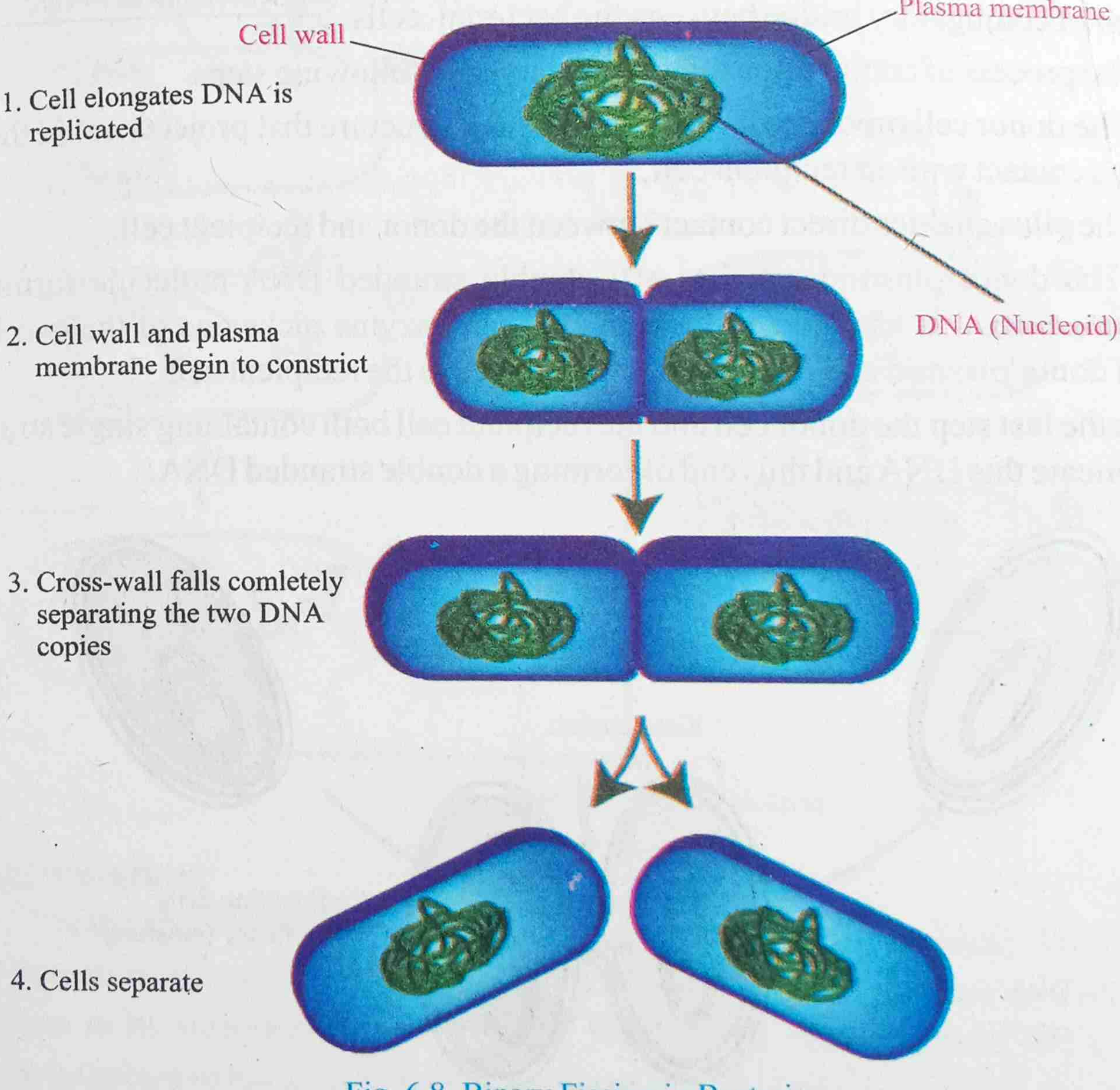


Fig. 6.8 Binary Fission in Bacteria

Sexual Reproduction in Bacteria:

Bacteria lack traditional sexual reproduction (gametogenesis). However, bacteria exhibit genetic recombination that is cells do not fuse, only piece of DNA or plasmid of donor cell is inserted in the recipient cell. This process occurs by conjugation,

transduction and transformation.

Conjugation:

It is the process by which one bacterium transfers genetic material to another bacterium through a tube formed by pili called conjugating tube or bridge. The bacterium that gives the DNA is called **donor** and the bacterium that receives DNA is called the **recipient.** This process was, first studied experimentally by Lederberg and Tatum in 1946 in *E. coli*. Later studies made with the help of electron microscope confirmed the close contact and the formation of conjugatory bridge between the bacterial cells.

Tit bits

A cell possessing the F plasmid (F+, Male) can form a conjugation bridge to cell lacking the F plasmid (F-, Female) through which genetic material may pass from one cell to another. Now F- cell has its own fertility plasmid and it becomes an F+ cell.

The process of conjugation may be explained in following steps.

Step 1: The donor cell produces the pilus, which is a structure that projects out of the cell and begins contact with an recipient cell.

Step 2: The pilus enables direct contact between the donor and recipient cell.

Step 3: The donor plasmid consists of a double stranded DNA molecule forming a circular structure, it is attached at the both ends, an enzyme picks one of the two DNA strands of donor plasmid and this strand is transferred to the recipient cell.

Step 4: In the last step the donor cell and the recipient cell both containing single stranded DNA, replicate this DNA and thus end of forming a double stranded DNA.

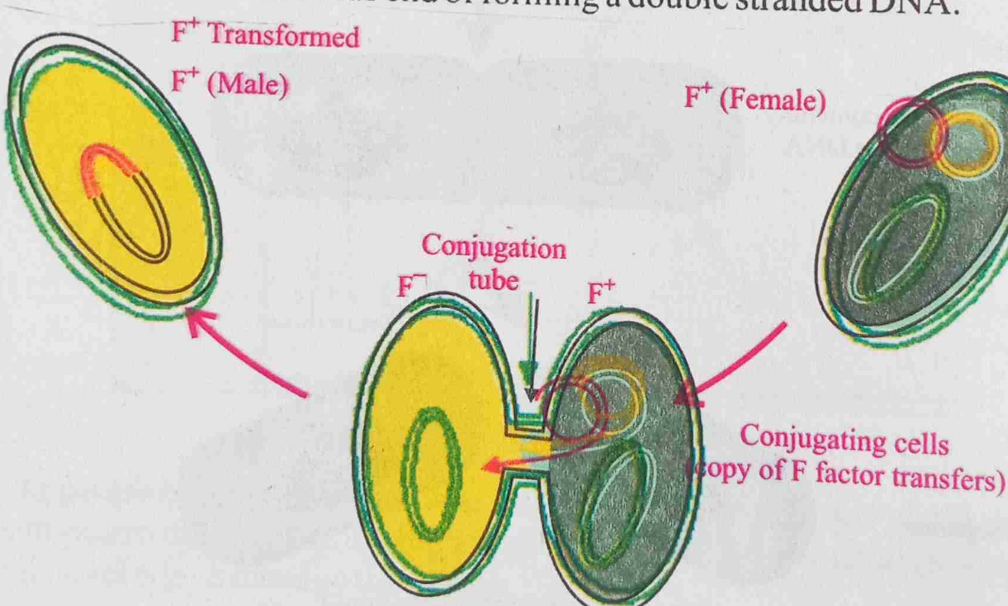


Fig. 6.9 Conjugation in Bacteria

Transduction:

It is a type of sexual reproduction, in which piece of DNA can be transferred from one bacterium (donor) to another bacterium (recipient) by a third organism, the

bacteriophage. The process of transduction was discovered by Norton Zinder and Joshua Lederberg in 1952 while studying the genetic recombination in *Salmonella*.

In general transduction, any of the genes from the host cell may be involved in the process, in special transduction, however, only a few specific genes are transduced.

> **Tit bits**
>
> *There are typically 40 million bacterial cells in a gram of soil and 1 million in 9 ml of fresh water and $5x10^{30}$ bacteria on earth.*

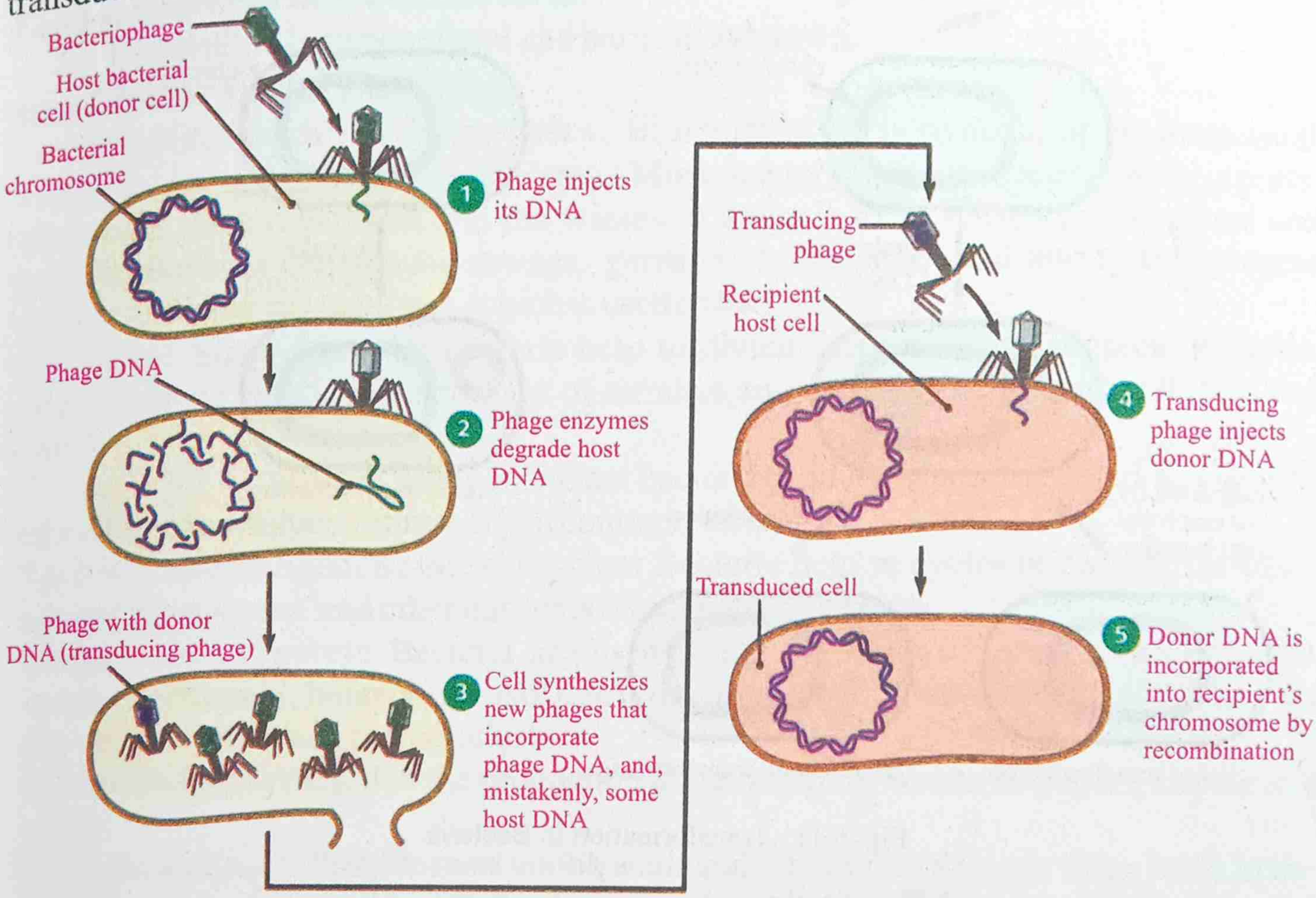


Fig. 6.10 Transduction in Bacteria

Transformation:

It is the absorption of DNA from a solution into a bacterium (cell). These cells are called transformed cells. The fragments of DNA are released after the death of a donor bacterium to its surrounding environment. Now if one of the released DNA fragment contacts a species of bacterium that is capable of transformation. The DNA fragment may be bound to recipient and is taken inside.

Griffith (1928) proved the process of transformation while experimenting on *Pneumococcus,* the bacteria which causes pneumonia.

Receptivity for transmission is present for a brief period when the cell have

reached the end period of active growth. At this time they develop specific receptor site in the wall. Normally *E. coli* does not pickup foreign DNA but it can do so in the presence of calcium chloride.

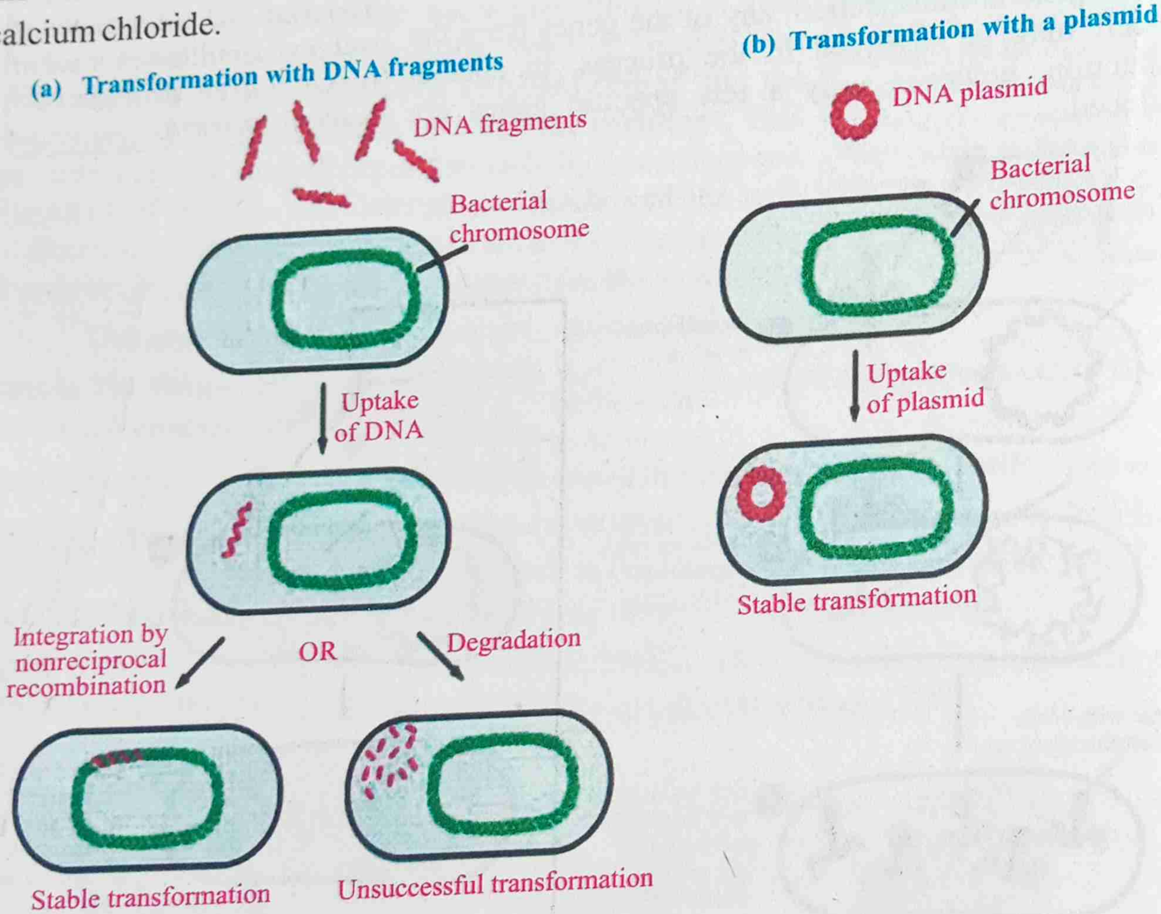


Fig. 6.11 Transformation in Bacteria

6.7 Importance of Bacteria

- Bacteria live everywhere because they have ability to survive in all conditions.
- They can adjust themselves according to environment, thus exhibit great ecological and economic importance, they are useful as **recyclers** of nature.
- Many bacteria involve in the steps of **nutrient cycles** e.g., carbon cycle are controlled by bacteria because of decomposition of remains of dead organisms. Denitrifying bacteria play role in denitrification .
- The genus *Rhizobium,* live in root nodules of legume plants converts nitrogen gas into nitrates.
- If bacteria were not present in universe, the CO_2 from the atmosphere would have diminished. Thus there would have been no photosynthesis and no possibility of life on earth.

6.7.1 Ecological Importance of Bacteria

The decomposition of dead organisms and wastes is carried out mostly by bacteria and fungi, which convert organic matter into humus. It contains nutrients and increases soil fertility for the growth of plants. Humus also retains water, thus increases water holding capacity of the soil. The **leguminous plants** have mutualistic association with the bacteria (Root nodules) which transform nitrogen into nitrates.

Economic Importance of Bacteria:

Bacteria are both beneficial and harmful to human.

Beneficial or Useful Bacteria:

Bioremediation and Decomposers: Bioremediation is removal of environmental pollutants by using living organisms. Most bacteria act as decomposing agents, decompose dead organisms and the wastes of animals to be reused by the plants and animals. Bacteria decompose sewage, garbage, dungs, stool and during this process produce methane gas or biogas, which is used as fuel.

Digestion: Some intestinal bacteria help to divide fats into small droplets in cattle, others produce cellulase, (in the gut of termites and cattle) which digest cellulose and starch.

Synthesis of Vitamins: Many intestinal bacteria produce vitamins, B and K. Bacteria are cultured to produce vitamin B_{12} on commercial scale.

Bacteria and Biogeochemical Cycles: Bacteria help in cycles of carbon, nitrogen, sulphur, phosphorus and other nutrients through the biosphere.

Bacteria in industry: Bacteria are used in the synthesis of vinegar (acetic acid), acetone, lactic acid, butanol (alcohol), several vitamins and flavoring tobacco. They are also used in leather and coffee industries.

In food industry: Used in the production of dairy products such as yogurt, cheese and butter.

Bacteria as Food: Provide most amino acids and vitamins to animals when enter in the alimentary canal through partially digested plant materials. A **single cell protein** is obtained from the large scale growth of microorganisms such as bacteria.

Antibiotics: Several antibiotics are obtained from actinomycetes group, e.g., streptomycin, teramycin and aureomycin.

Genetics: Bacteria are used for studying the principles of genetics, such as *E. coli*.

Harmful Bacteria:

Bacterial Diseases in Plants: Parasitic bacteria infect plants and cause various diseases, e.g., fire blight in apple and pear, ring disease in potato and crown galls.

Bacterial Diseases in Man: Many human diseases are caused by bacteria; like tuberculosis, diphtheria, tetanus, cholera, leprosy, typhoid fever, meningitis, sore throat, whooping cough etc.

Bacterial Diseases in Animals: Chicken cholera, anthrax, TB etc.

using ...

6.8 The Bacterial flora of human

Flora: It is the plant life occurring in a particular region at a particular time.

The **normal flora** is the population of micro-organisms routinely found growing on the body of healthy persons.

Resident flora: live for extended period in the body of infected person.

Transient flora: temporarily live.

Many microorganisms make up normal flora, which occur in large number. In fact, there are more bacteria in just one person's mouth than there are people in the world.

Table 6.3 Some Members of Normal Bacterial Flora

Members of Normal Flora	Anatomic Location
Clostridium species	Colon
Escherichia coli, Lactobacillus	Colon, vagina, outer urethra
Lactobacillus species	Mouth, colon, vagina, uterus
Staphylococcus aureus, Corynebacterium	Nose, skin, respiratory tract, tongue
Enterococcus faecalis, E. coli	Colon, (Predominantly intestinal bacteria)
Viridans streptococci	Mouth, nasopharynx.

Benefits of normal bacterial flora to Human

(1) Normal flora protects us against potentially harmful microorganisms.

(2) The normal flora also plays an important role in the development of immune responses.

(3) Produces some nutritional substances. Many intestinal bacteria produce vitamin B and K.

6.9 Control of Harmful Bacteria

Microorganisms can be controlled by physical or chemical methods.

Physical methods

Sterilization: This method is useful to kill all life forms, in which physical agents like steam, dry heat, gas filtration and radiations are used. It is the destruction of all life forms. It is used to sterilize surgical instruments. It is also used to preserve milk and meat on large scale.

High temperature: This method is used in microbiological laboratories in which both dry and moist heat are effective. Moist heat helps in coagulation of proteins and kills the microbes. Dry heat causes oxidation of chemical constituents of microbes and kill them.

Radiation: Microbes are killed by electromagnetic radiation below 300 nm. Gamma rays are generally used for this purpose.

Membrane filter: Heat sensitive materials like antibiotics, sera, hormones, growth media, enzymes, vitamins can be sterilized by using membrane filters. In hospitals some operation theaters and burn wards receive filtered air to lower the number of air borne microbes.

Pasteurization: This process was developed by Louis Pasteur to kill non-spore forming bacteria, e.g., milk is pasteurized by heating at 71°C for 15 seconds and at 62°C for 32 minutes to destroy Tuberculosis and Typhoid bacteria in milk. Pasteurization does not change the taste of milk.

Low temperature: Low temperature **(10-15°C)** can preserve food for several days, such as milk, egg, meat, cheese and vegetables.

Freezing: Meat and some vegetables can be prevented from microbial destruction by freezing at below **0°C (-10 to -18°C)** for several weeks to several months.

Drying: In this method water is removed from food like meat, milk, vegetables etc, thus bacteria can not grow because their enzymes need water for action.

Preservatives: Many preservatives stop the growth of microbes, e.g., **Acid** lowers the pH, salts and sugar decrease water in food, the reduced water checks the growth of bacteria.

Certain chemicals: Like potassium metabisulphate stops bacterial growth when added in pickles, candies, jams, bread and biscuits.

Chemical methods to control bacteria:

Following chemical methods are used to control microbes.

Antiseptics: There are certain chemical substances (such as iodine, Dettol) that stop the growth of microbes called antiseptics.

Disinfectants: Certain chemicals like halogens and phenols, H_2O_2, potassium permanganate, alcohol and formaldehyde etc., are oxidizing and reducing agents that inhibit the growth of vegetative cells and are used on non-living materials.

Chemotherapeutic agents: Certain chemicals and antibiotics destroy and stop the growth of microbes in cells, e.g., penicillin, tetracycline etc.

6.10 Cyanobacteria

Why cyanobacteria are considered as the most prominent of the photosynthetic bacteria?

Cyanobacteria played major role in the evolution of life. They were the first oxygen producing organisms. Their photosynthetic activity gradually oxygenated the

atmosphere and the oceans about two billion years ago. The level of oxygen increased by cyanobacteria, i.e. to about 21%. The amount of **ozone** also increased in the upper layers of the atmosphere by cyanobacteria. Ozone acted as a screen to protect the nucleic acids and proteins from destruction by ultra violet radiations from the sun.

It encouraged other autotrophs to appear and survive on earth. Many of cyanobacteria (about one third) are involved in the **fixation of atmospheric nitrogen** to produce nitrates e.g., Anabaena and Nostoc are purposely cultivated to increase the soil fertility, because of nitrogen fixation ability of these organisms.

Characteristics of Cyanobacteria

Habitat: These are found in damp places, salt water, fresh water, in moist soil, hot springs (with temperature up to 85°C).

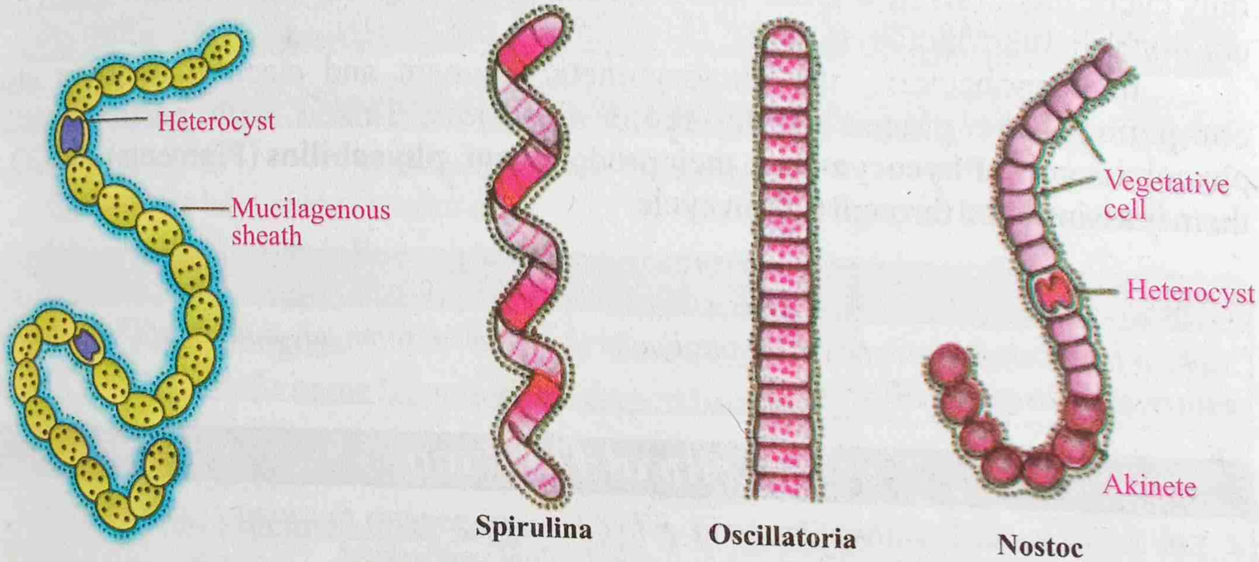


Fig.6.17 Examples of Cyanobacteria

Mode of life: May be epiphytic and symbiotic.

Form of life: May be unicellular and solitary, exist as colonies of many shapes, or form filaments consisting chains of cells (trichomes) surrounded by mucilaginous sheath.

> **Do you know?**
> *Bacterial cell membrane lacks cholesterol.*

Cell wall is Gram negative type (contains lipopolysaccharides, lipoproteins, peptidoglycan).

Photosynthetic System closely resembles to eukaryotes because cyanobacteria have chlorophyll *a* and photosystem II, use water as an electron donor and generate oxygen during photosynthesis. They have phycobilins as accessory pigments. Phycocyanin is their predominant pigment. The photosynthesis takes place in the extensive system of membrane, which is placed in the periphery of the cytoplasm.

6.10.1 Pigment Composition in Cyanobacteria

Cyanobacteria possess two accessory pigments, i.e., phycocyanin (blue pigment) and phycoerythrin (red pigment). In some species the mixture of chlorophyll and blue pigment, produces the blue green color, thus sometime known as blue green algae. But the other species contain red pigments, appear red, purple brown or even black.

6.10.2 Difference between the photosynthetic mechanisms in cyanobacteria and photosynthetic bacteria.

The photosynthetic bacteria release sulphur whereas cyanobacteria release oxygen during photosynthesis. The source of hydrogen in bacteria is hydrogen sulphide whereas cyanobacteria like plants obtain hydrogen from water.

The photosynthetic bacteria have photosystem I but lack photosystem II, thus only cyclic electrons flow is the sole means of generating ATP while cyanobacteria have chlorophyll *a* and photosystem II.

In cyanobacteria, the photosynthetic pigment and electron transport chain components are placed in thylakoid membrane linked with particles called phycobilisomes. **Phycocyanin** is their predominant **phycobilins** (Pigments) and CO_2 in them is assimilated through Calvin cycle.

Activity

Make a list of characteristics of Cyanobacteria and write some advantages of Cyanobacteria with respect to soil fertility.

Critical Thinking

1. *Life is not possible without bacteria. Why? Give arguments to support this statement.*
2. *Why bacteria are widely used in biotechnological processes?*

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A. **Choose the best correct answer.**

1. Which of the following term describes most of the bacteria?
   (a) Anaerobic (c) Many-celled
   (b) Pathogens (d) Beneficial
2. What is the name for spherical-shaped bacteria?
   (a) Bacilli (c) Spirilla
   (b) Cocci (d) Colonies
3. What structure allows bacteria to stick to surfaces?
   (a) Pili (c) Chromosome
   (b) Flagella (d) Cell wall
4. Which of these organisms are recyclers in the environment?
   (a) Producers (c) Saprophytes
   (b) Carnivores (d) Pathogens
5. Which of the following is caused by a pathogenic bacterium?
   (a) AIDS (c) Nitrogen fixation
   (b) Cheese (d) Tetanus
6. Which of the following cannot be found in a bacterial cell?
   (a) Ribosomes (c) Chromosome
   (b) Nucleus (d) Cytoplasm
7. Which organism of the following can grow as blooms in ponds?
   (a) Archaebacteria (c) Cocci
   (b) Cyanobacteria (d) Viruses

8. A bacterium with a tuft of flagella at one side of the body.

(a) Lophotrichous (c) Peritrichous

(b) Amphiptrichous (d) Non of the above

9. Asexual reproduction in bacteria is called.

(a) Budding (c) Multiple fission

(b) Binary fission (d) Both A and B

Fill in the blanks.

1. Pili are made of protein called ________.
2. Flagella are made of a protein called ________.
3. The cell wall of bacteria is made of ________.
4. ________ are straight or rod shape bacteria.
5. Bacterium having single flagellum is called as ________.
6. The bacterium that gives the DNA during conjugation is called ________
7. Typhoid is caused by ________.
8. Tuberculosis is caused by ________.

in the same soil again and again. The possible remedy for this problem is addition of fertilizers in soil and cultivation of different crops alternatively in the same soil as well as cultivation of legume plants along with normal crops.

10.1.1 Nutrition in Carnivorous Plants

Insectivorous or carnivorous plants are those types of plants that obtain some of their nutrients especially nitrogen by consuming insects or protozoans. These plants are adapted to grow in places where the soil is thin and poor in nutrients. The insectivorous plants include the **Venus fly trap, pitcher plants** ***(Nepenthes)*****, butterworts, sundew, cobra lily** and hundreds of others. However, these plants do not depend entirely on insects and small animals for their nutrition. The main source of energy is their autotrophic mode of nutrition like other plants. These plants trap insects and small animals just to fulfill their mineral nutrient deficiency. These plants have special traps to capture prey and enzymes to digest the prey.

Fig. 10.1 Insectivorous plants

- Describe obesity in terms of its causes, preventions and related disorders.
- Explain the symptoms and treatments of bulimia nervosa and anorexia nervosa.

Introduction

Nutrients are food substances which are used by an organism as a source of energy and necessary elements for the maintenance of life and growth. The food is utilized at the cellular level, but most organic food except vitamins are present in large complex and non diffusible, thus cannot be absorbed in the cell. Therefore these large complex food particles must be broken down into simple and diffusible food, so that these molecules can easily pass through the wall of intestine into the blood then upto the cells.

11.1 Digestive System of Man

The digestive or gastrointestinal tract of human consists of about 9 meters (30 feet) long tube. The digestive system, can be divided into two main parts:

The **alimentary canal or digestive tract** or gastrointestinal tract (GIT) and **associated or accessory glands**. Alimentary canal consists of oral cavity, pharynx, oesophagus, stomach, small and large intestine, anal canal and anus while accessory glands are salivary glands, gastric

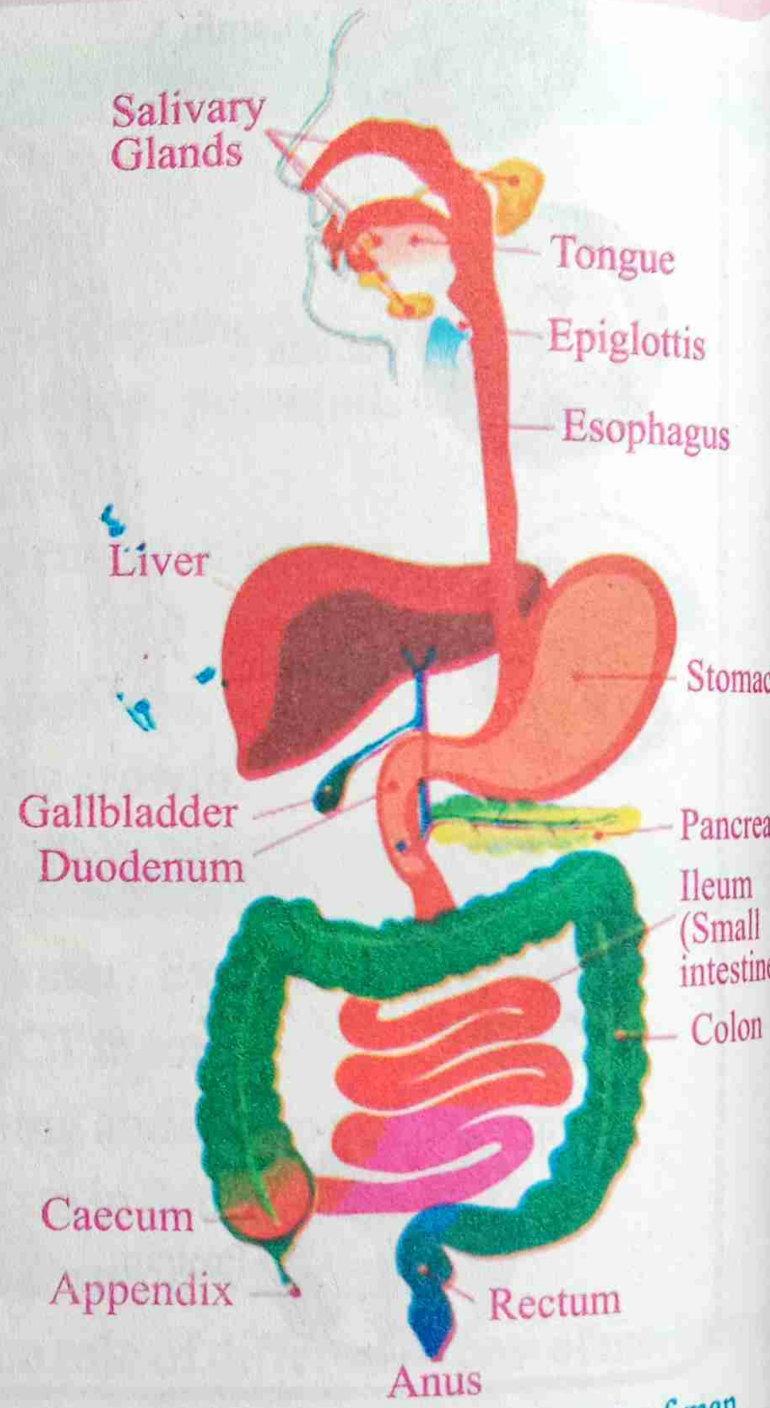


Fig. 11.1 Digestive system of man

glands, liver, pancreas and intestinal glands.

Entire alimentary canal consists of three main layers (tunics), an internal epithelium, mucosa and submucosa, muscular layers and external serosa.

Oral Cavity or Buccal Cavity:

The opening of oral cavity is mouth. The mouth is bounded by upper and lower lips. The oral cavity contains upper and lower jaws, palate, tongue and **salivary glands**. The salivary glands are present in three pairs, **sub lingual, sub mandibular and parotid glands.** These glands secretes saliva into the oral cavity. The tongue is muscular organ and is attached to the floor of oral cavity, it is freely movable and bears many taste buds. The roof of oral cavity is called **palate**, which is hard in anterior and soft at posterior.

Pharynx:

It is the posterior part of the oral cavity extended upto oesophagus and larynx, gives passage to air and food.

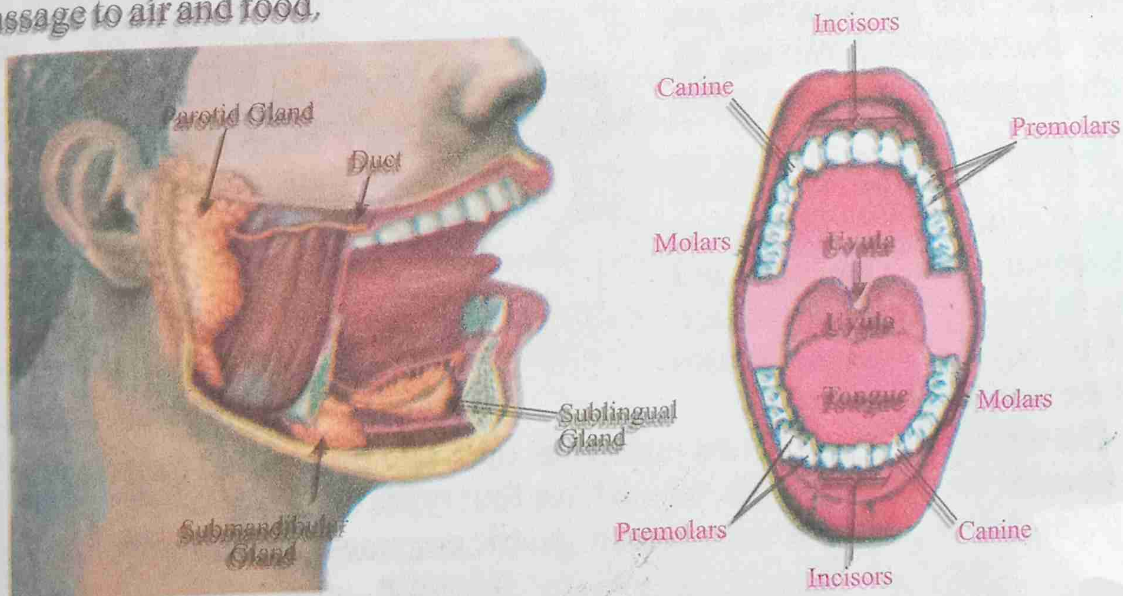


Fig. 11.2 Salivary glands and upper and lower jaws

Oesophagus: (means passage way).

It is a muscular tube which extends from pharynx to the neck, thorax and enters into the stomach through the oesophageal aperture of the diaphragm. The oesophagus shows characteristics waves of contraction known as **peristalsis**, which help to drive the food towards the stomach.

> **Tit bits**
>
> *Both jaws bear 32 permanent teeth (20 milk teeth), embedded in their sockets in the gums, teeth are of four types i.e., incisor 2/2 canine 1/1, premolar 2/2, and molar 3/3.*
>
> *Teeth help in grasping and grinding of food.*

Stomach:

Stomach is **widest part of digestive tract,** located at left side of abdomen, below the diaphragm. It is roughly J-shaped and consists of four prominent regions i.e.,

cardiac, fundus, body and pyloric regions. Cardiac sphincter (a ring type muscle) present at the cardiac end of stomach and oesophagus while pyloric sphincter at the opening of stomach into the duodenum both sphincter prevent backward flow of food.

Tit bits

Tooth decay and Gum bleeding are very common human diseases. Make a list of their main causes and possible remedies of these diseases through the different sources available to you.

Layers of stomach: The inner most layer of stomach is **epithelium** below it is **mucosa**, consists of connective tissues, rich in blood vessels, glands and nerves. Next to mucosa is **submucosa** having outer longitudinal muscles, inner circular and inner most oblique muscles. The contraction and relaxation of these muscles are responsible for grinding, churning and mixing of food with the help of enzymes in the stomach.

Serosa: It is the thin outermost layer which connects the stomach to the abdominal wall. The folds and wrinkles in the wall of the stomach are called **rugae**, which increases the surface area of the stomach.

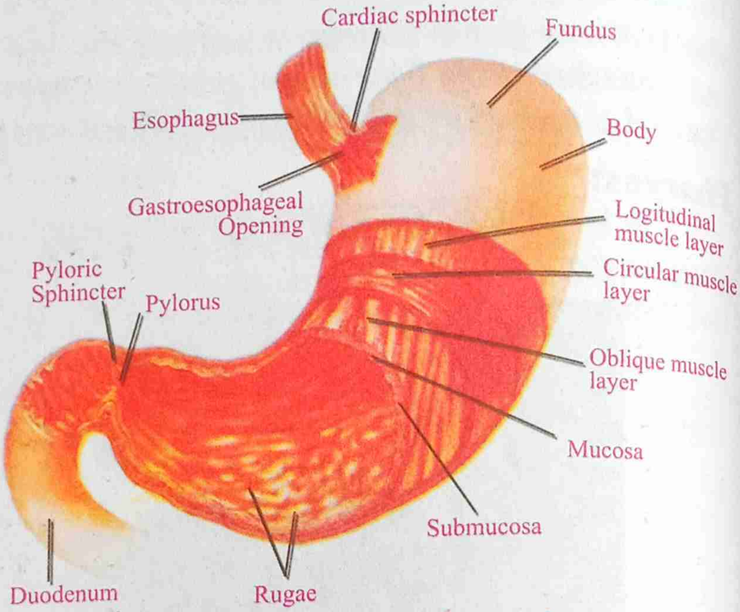


Fig. 11.3 Anatomy of stomach

The mucosal surface forms numerous tube like pits, called **gastric** pits. The pits are the opening for gastric glands, which have four types of cells.

a) Zymogen or principal cells, secrete gastric enzymes (pepsinogen).

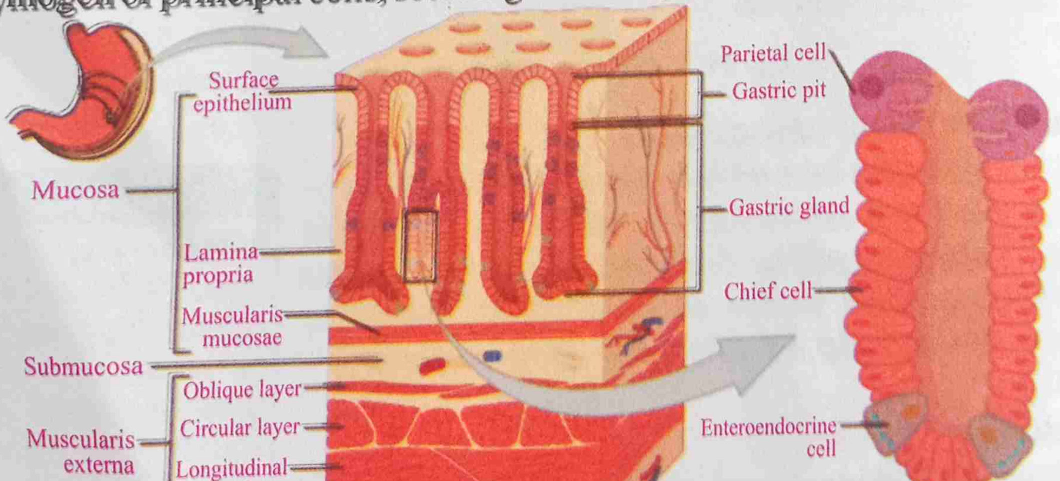


Fig. 11.4 Longitudinal section of stomach wall

Oxyntic cell or parietal cells, secrete hydrochloric acid.

b) Goblet cells secrete protective mucus.

c) Endocrine cells secrete gastrin hormones.

d) **Small intestine:** Small intestine begins from end or pylorus of stomach, it is highly coiled tube about 6 to 7 meter long and about 2 to 4 cm in diameter. The small intestine consists of three parts, duodenum, jejunum and ileum.

Duodenum (Latin Twelve fingers breadth in length) is the first part of the small intestine, starts from pylorus of stomach and is "C" shaped, about 20 to 30 cm in length. It receives two alkaline fluids from liver and pancreas by a common duct called the **hepatopancreatic ampulla.**

Jejunum (Latin empty and hungry) is the second part of the small intestine, about 2.5 meter long.

Ileum (Latin twisted or coiled) is third part of small intestine, about four meter long. Ileum is highly convoluted and major part, where food is digested and absorbed. It contains **Brunner's gland** which produce intestinal juice. There is no clear cut demarcation between jejunum and ileum, except there is gradual decrease in the diameter of small intestine and thickness of its wall.

> **Tit bits**
>
> ***Appendicitis:***
> *It is an inflammation of appendix, occur due to entrapping of undigested food, which on decomposition cause pain, thus must be removed through surgery before bursting.*

The internal lining of the small intestine is thrown into numerous finger like tiny projection called **villi** that increase the surface area for absorption of nutrients. Each villus contains blood capillaries, lacteal vessels covered with columnar epithelial cells and have mucus secreting goblet cells.

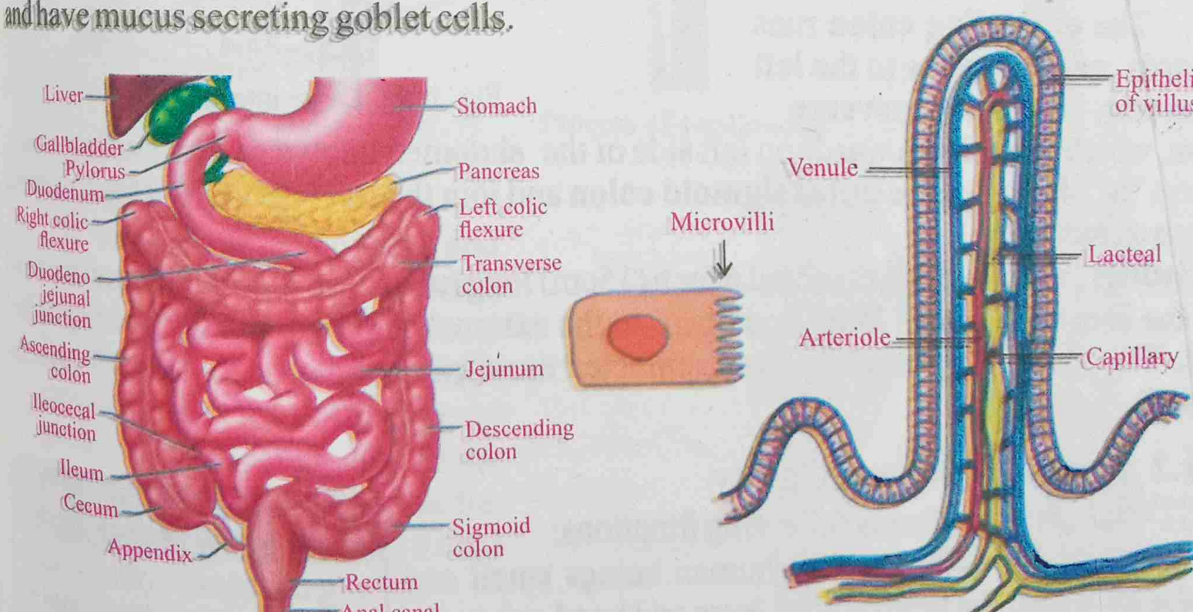


Fig. 11.5 Small, Large Intestine and Villus

There is **ileocecal** sphincter between ileum and caecum which prevent backward flow of undigested food from large intestine.

Large intestine: The large intestine is a wide tube which begins from the ileum of small intestine and ends to anus. It is about 2 meter long and divided into three parts i.e., caecum, colon and rectum.

Activity

How the large sized digestive tract is beneficial for human.

Humans are not carnivorous, still canines are present in their jaws can you guess why?

Tit bits

Antiperistalsis:

The reversal of peristalsis is called antiperistalis which results in vomiting The cause of this reversal is irritation in the oesophagus or stomach due to intake of toxic food.

Caecum: (Latin blind sac) It is a blind pouch, present between ileum and colon, extend about 6 cm behind the ileocecal junction, attached to the caecum a blind finger like projection known as vermiform appendix, which is non functional in man and about 10 cm long.

Colon: The colon is second part of large intestine, about 1.5 to 1.8 meter long and consists of four parts.

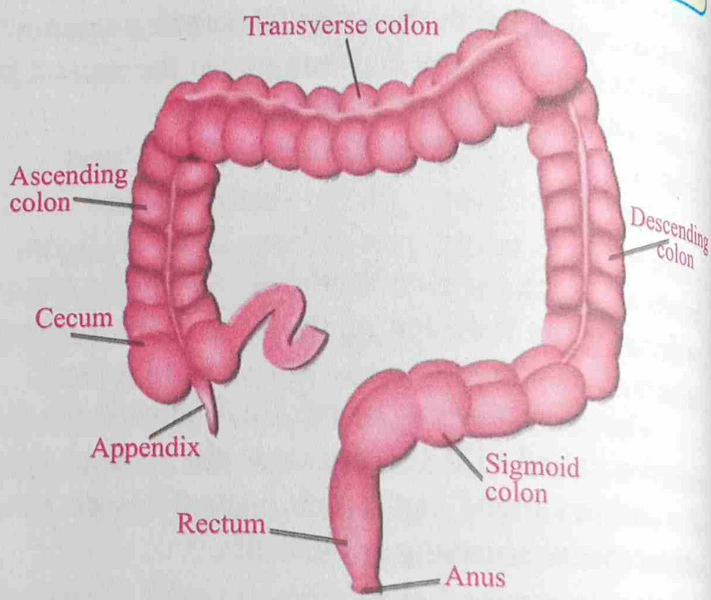


Fig. 11.6 Large intestine

The **ascending colon** runs upwards and then runs to the left transversly is called **transverse colon**, which goes down wards on left side of the abdomen known as **descending colon**. It form "S" shaped curve called **sigmoid colon** and join the last part of the large intestine known as rectum.

Rectum (L. rectus; straight) about 6 inch (15cm) long tube, runs straight downwards and join the anal canals(4cm long) and open to the external skin by a round opening called anus. The anus is guarded by two sphincter muscles (internal smooth and external striated).

11.1.2 Function of Oral Cavity

Oral cavity performs following functions:

Selection of food: First of all human beings smell and feel the food with the help of nose, eyes and hand, when the food enters the oral cavity it is tasted by tongue. The teeth and tongue help to find any hard object in the food e.g., piece of bone and stone.

Do you know?

A bolus (from Latin bolus = ball) is a ball like lump of food and saliva that forms in the mouth during the process of chewing.

Grinding of food: The food is chewed by ripping, crushing and grinding. These occur with the help of premolar and molar teeth, so can be easily passed through oesophagus and increase surface area for enzymatic action.

The salivary glands secrete mucus and saliva, mucus lubricates the food while sodium bicarbonate and other salts in the saliva are slightly antiseptic and kills the germs taken along with the food. It also maintains pH of food to alkaline level. The saliva also contain enzyme salivary amylase which digests the starch and glycogen, converts these into maltose.

Swallowing of food:

The semi digested and lubricated food arranged into small oval masses called bolus. The bolus are now pushed down into the pharynx and oesophagus by combined efforts of cheek muscles, floor of buccal cavity and tongue.

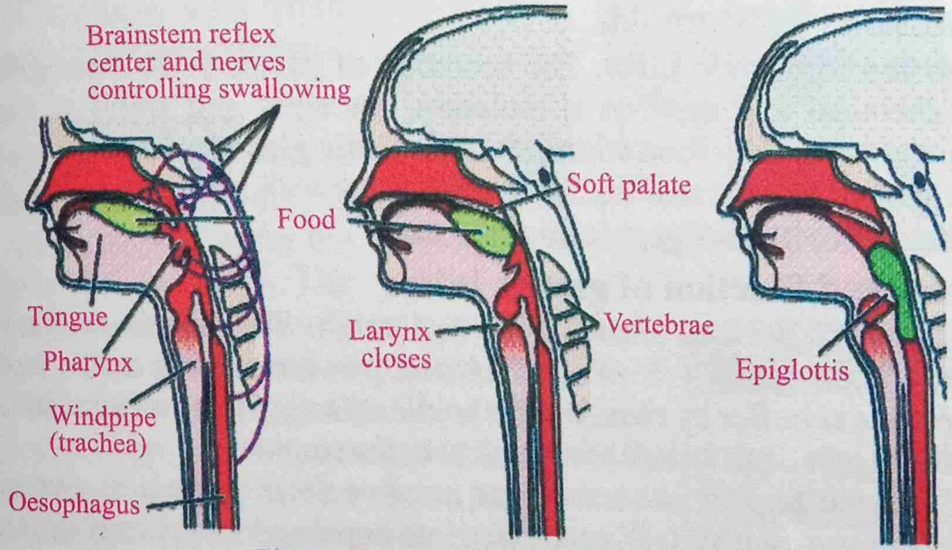


Fig. 11.7 Process of swallowing

Steps of swallowing:

i) The tongue move upward and backward for forcing the bolus towards the pharynx.

ii) The backward movement of the tongue pushes the soft palate up to close the nasal passage. At the same time the tongue forces the epiglottis into horizontal position to close the glottis.

iii) Larynx move upwards under the back of tongue. The glottis is partly closed by the contraction of ring muscles.

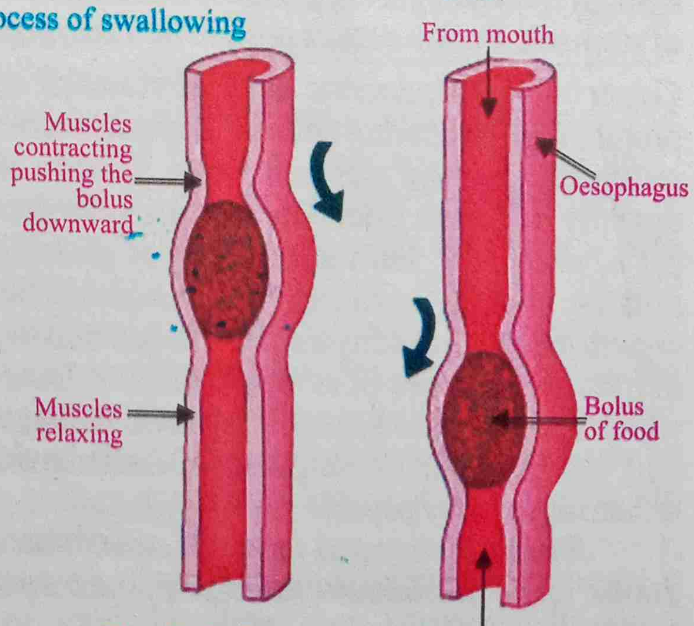


Fig. 11.8 Peristalsis

iv) The main muscles of pharynx contract and initiate peristalsis.

11.1.3 Function of Oesophagus

Oesophagus pushes the food from pharynx to stomach through the process of peristalsis, the salivary enzymes keep its action continue.

Peristalsis: (Gk. Peristalikis; to wrap around)

It is the movement of the gut to move the food to lower side. It consists of waves of contraction of circular and longitudinal muscles, preceded by waves of relaxation in circular muscle behind the bolus contract and a mechanical pressure propels the food, the circular muscle is relaxed in front of the bolus, thus the bolus move forward. Then the next one contract while the first one relax and so on.

11.1.4 Function of Stomach

Secretion of gastric juice. The secretion of gastric juice from gastric gland is caused by chemical and nervous stimulation, the sight and smell of food is also a stimulus. In the oral cavity food stimulates the gastric gland by impulse, more juices are secreted by gastric gland when the food touches the wall of the stomach. Adult human produces about three liters of gastric juice per day.

Composition and function of gastric juice:

It consists of mucin, pepsin, HCl and renin. The **mucin** forms a protective covering around the inner wall of stomach and prevent it from acidic and enzymatic action. It also acts as buffer by reducing the acidic effects of gastric juice for some time, if this protecting mechanism fails, it causes ulcer in the stomach.

The enzyme **pepsin** is secreted as inactive form known as pepsinogen from zymogen cells of gastric gland. It is activated into pepsin when exposed to acidic medium of stomach. Pepsin breaks protein into polypeptides and dipeptides.

Gastrin: The endocrine cells of stomach secrete gastrin, If our food contains more protein than endocrine cells of stomach secrete gastrin, which diffuses in the blood and return back to the stomach again. Gastrin stimulates gastric glands to secrete large quantity of gastric juice.The **oxyntic cells** secrete **HCl** in high concentration form with pH of about 1.3, but the final pH of gastric juice of stomach becomes 2 to 3 due to dilution. Acidic environment of stomach stops the reaction of ptyalin, kill micro organisms in food, activate pepsinogen into pepsin, also control the opening and closing of **pyloric aperture** of stomach. Gastric Juice also contains **prorenin** (more in infants) which become active to renin by HCl, it coagulate the casinogen, the soluble protein of milk into insoluble calcium salts of casein in the presence of calcium chloride ions which is then digested by pepsin.

The semi digested food of stomach becomes soupy mixture known as chyme. It passes to the duodenum through pyloric opening, when reaches a certain degree of acidity.

11.1.5 Function of Small Intestine

Most of digestion and absorption of nutrients occurs in small intestine. When food enters from stomach into duodenum, the acidity of food stimulates the pancreas and liver to secrete bile and pancreatic juices that are poured into the duodenum. The intestinal mucosa also secretes mucus and enzymes that remain associated with the intestinal epithelial surface. The mucus protects the intestinal wall from acidic chyme and digestive enzymes.

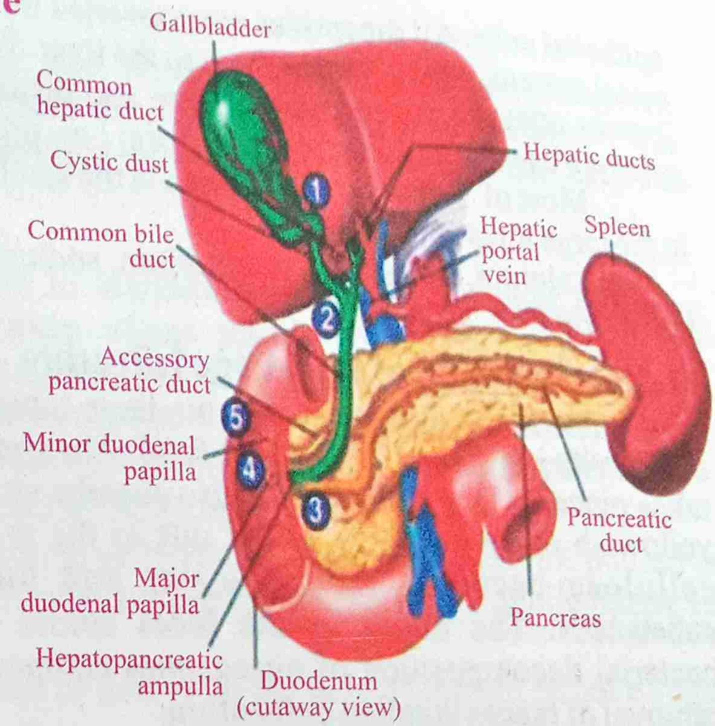


Fig. 11.9 Associated Glands of Digestive System

Pancreatic juice:

It is slightly alkaline with a pH-8 and neutralize the acidic chyme of, provides suitable medium for the action of digestive enzymes. The pancreatic juice contains, many enzymes such as pancreatic amylase which converts starch into maltose and glucose. **Trypsin** is also secreted as inactive **trypsinogen,** which is activated by enterokinase, secreted by the lining of duodenum. It breaks proteins into peptone and polypeptides. Sodium bicarbonate partly neutralizes the acidic chyme coming from the stomach. The digestion of lipids is initiated in small intestine, firstly **bile,** secretion of liver emulisifies the fats then **lipase** secreted by pancreas digests lipid molecules. The primary products of this digestive process are free forms of fatty acids and glycerol. Phospholipids and cholesterol are also present in digested products. When lipid is digested in the intestine bile salts aggregate around the small droplets to form **micelles** (small morsel). The micelles passes by means of simple diffusion through epithelial lining of small intestine. In the intestinal epithelial cell, triacylglycerol is formed which become **chylomicrons** (lipoprotein) when mixed with proteins. The chylomicron leaves the epithelial cell and enters the lacteals of the lymphatic system within villi of intestine. From lymphatic system, it is poured in blood stream and before entering lipid storing tissues i.e., adipose tissues, triglyceride is broken down into fatty acids and glycerol. In adipose tissue these are again converted into triglycerol.

> **Do you know?**
>
> *Chyle from Greek word chylos juice, means a milky body fluid consisting of lymph and emulsified fats formed in small intestine during digestion.*

The peptone and polypeptide chains are broken down into **dipeptide,** amino acids by peptidase bound to the **microvilli** of small intestine, then enters the intestinal

epithelial cells. All dipeptides are converted into aminoacids before entering the hepatic portal system, which carries them to the liver. The amino acids are either modified in the liver or released in the blood stream and distributed to entire body cells where amino acids are used as building blocks to form new proteins or used for energy.

Most of the water is absorbed in the small intestine and about 6 to 7 % is absorbed in the large intestine.

Calcium, potassium, magnesium, sodium and phosphorous ions are also actively transported.

11.1.6 Function of the Large Intestine

The material that reaches the large intestine contains water and dissolved salts along with waste and undigested food. Absorption of water and salts from the chyme takes place by large intestine. It also absorbs vitamin K and B. The remaining chyme is yellowish or brownish in colour due to the presence of bile pigments. It consists of cellulose bacteria, mucin, water and undigested substances. The odour of the feces comes from the bacterial decomposition of nitrogenous compounds. The removal of faeces is called **defecation.**

> **Tit bits**
>
> ***Constipation:***
> *Slow passage of wastes in large intestine result hardening of faeces. This cause constipation.*

Movement in the large intestine takes place:

The peristaltic waves push the chyme into the ascending colon. Distention of the rectal wall due to deposition of feces acts as a stimulus that initiates the defecation reflex.

The external anal sphincter (composed of striated muscles) is consciously controlled, prevents the movement of feces out of the rectum and through the anal opening. If this sphincter is relaxed voluntarily, feces is expelled.

> **Activity**
>
> *Why it is advised not to drink water right after meal? give medical/scientific reason.*

In infants, the defecation reflexe is involuntary, (unconsciously controlled).

11.2 Function of Accessory Glands

Liver: Liver is the largest internal organ and gland of the body, dark red in color, situated on the right side of the abdomen below the diaphragm. It is bilobed, the right lobe is larger than the left lobe. Liver is formed of hepatic cells. A pear shaped, sac like structure called **gall bladder** lies along the right side of liver, where the secretion of liver called bile is stored temporarily. The hepatic ducts transport bile out of the liver. The right and left hepatic ducts unite to form a single common hepatic duct. The common hepatic duct is joined by the cystic duct to the gall bladder to form the common bile duct, which empties into the duodenum at the major **duodenal papilla** in union with the pancreatic duct.

Function of liver: The liver have many roles in the body such as digestive and excretory function. It stores and processes nutrients, synthesizes new molecules and detoxifies harmful substances.

11.2.1 Composition of Bile

The secretion of liver is known as bile. It does not contain digestive enzymes, rather consists of water, bile salts, (sodium glycolate and sodium taurocholate) **bile pigment** (Bilirubin and biliverdin) lecithin (*Phospholipid*), cholesterol, mucus cells and cell debris.

Role of Bile:

It emulsify the fats into droplets to increase surface area for lipid digestive enzymes **(lipase).** It contains **bilirubin** which results from the breakdown of haemoglobin. In the intestine, bacteria convert bilirubin into urobilinogen which give brownish color to feces and yellowish color to urine when absorb again in blood stream. Bile salts help in the absorption of fatty acid from intestinal tract to circulatory system.

Role of secretin hormone to regulate secretion of bile:

The duodenal endocrine cells secrete an hormone known as **secretin,** poured in the circulatory system and carry to the liver and stimulates the secretion of bile juices. Its secretion depends on fats and acidity .

Storage Role of liver: The hepatocytes of liver with the help of insulin remove sugar from the blood and store in the form of glycogen. It also stores fats, Vitamins (A, B12, D, E and K), copper and iron. The stored substances are reused whenever needed thus storage function is usually short term.

Metabolic role of liver: Liver is involved in metabolism of glucose. It converts surplus glucose in the form of glycogen **(glycogenesis),** whenever glucose is needed it changes glycogen into glucose **(glucogenesis).** the amino acids, fatty acids, glycerol and lactic acid are also changed into glucose **(gluconeogenesis).**

- Liver cells denature the fatty acids and phosphorylate fats.
- Liver helps in the deamination of amino acids synthesize vitamin "A" from carotenoid and synthesis of albumin from amino acids.
- The formation of clotting proteins (prothrombin and fibrinogen) also occurs in it.
- It breaks RBCs after completion of 120 days life span. In embryo liver helps in formation of RBCs. (i.e., fetal RBCs).
- The bile pigments bilirubin and biliverdin are formed from break down of haemoglobin.
- Liver is the center of heat production (i.e., **geyser of body).**
- **Detoxification** of poisonous substances and formation of heparin which prevent clotting of blood inside blood vessels.

11.2.2 Pancreas (Sweet bread)

It is a soft gland, grayish pink in color, situated transversely beneath the stomach. It acts as both endocrine and exocrine gland. From the exocrine cells, a duct arises called pancreatic duct, which joins the common bile duct then together opens into the duodenum. The secretion of this gland is known as pancreatic juice.

- The endocrine part of the pancreas consists of pancreatic islets. (islets of

Langerhans) which mostly secrete insulin and glucagon hormone .

The secretion of pancreatic juice is related to secretin hormone:

The hormone secretin controls the exocrine secretions of pancreas, which maintain pH of chyme in the intestine, by secreting watery solution that contains a large amount of bicarbonate ions.

11.3 Some Common Diseases Related to Digestive System and Food Habits

Some common disorders of digestive tract are as under.

11.3.1 Dyspepsia

Incomplete digestion is called dyspepsia.

Symptoms: Abdominal discomfort due to over production of gas in the stomach is called **Flatulence** i.e., distension of stomach by gases formed during digestion. Other symptoms are **heart burn, nausea** (feeling of vomit) and vomiting.

Causes or reasons (Aetiology)

- Gastritis inflammation of lining of stomach.
- Excessive acidity in stomach.
- Alcohol and smoking.
- Insufficient quality and quantity of bile secretions.

Prevention and Treatment:

Avoid smoking, reduce body weight, use of light and easily digestible food, avoid alcohol, tea, fatty food, avoid over eating.

Antacid for heart burning, antibiotic can be used. Histamine blocking agents, which check acid production, stop non-steroid anti inflammatory drugs (NSAID) e.g., Aspirin while the stomach is empty.

11.3.2 Food poisoning

An acute illness caused by eating food containing toxic substances (contaminated food), occurs with in 12-24 hours after eating.

Symptoms: vomiting, diarrhea (it is persistent loosening of bowels). It also cause abdominal pain, dizziness, fatigue, double vision, nausea, headache and dehydration.

> **Do you know?**
> *The persons with blood group "O" are more prone to peptic ulcer. It is also hereditary.*

Aetiology (Reasons):

This disease is due to intake of contaminated food which contains toxin, produced by certain bacteria, such as *Salmonella* and *Campylobacter.*

Human may develop food poisoning by taking the liquid from defrosting (remove ice) frozen meat contains *Salmonella* bacteria. It also contaminate the unpasteurized milk, egg and meat which are not cooked properly.

Prevention and treatment:

- Use only freshly prepared hot food or thoroughly rewarmed food.

- Physicians may treat water and salt deficiency which results from vomiting and diarrhea through oral rehydration solution (ORS).
- Loperamide antibiotic therapy against any infection can also be advised.
- The dishes and utensils should be washed before using.
- Unwashed fruits, precooked food should be washed before handling.
- Unsterilized water should not be used.

11.3.3 Obesity

When a person has over weight due to abnormal and excess body fat is called obesity.

Symptoms: An obese person mostly suffers from:

- Hypertension (high blood pressure).
- Heart disease (coronary heart disease).
- Diabetes mellitus.
- Bone pain in knees, hips and joints due to over weight.
- Stomach disorders.
- Gall bladder diseases.

Aetiology or Cause: When people eat more than their need, then excess calories are stored in their bodies as fats, so they become obese. The fats are mostly stored in adipose tissues in the abdomen. Genetic tendency is also a factor. Disorder of the thyroid, pituitary and adrenal glands, emotional disturbances also cause obesity.

Adipose tissue: Surplus food is stored in the form of fat droplets in cytoplasm. The droplets join and form large globule of fat in the middle of cell pushing the nucleus one side. Groups of fat cells form adipose tissues around the kidney and under the skin.

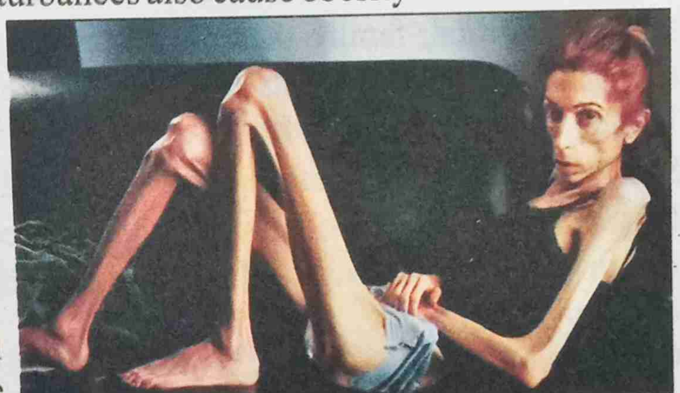


Fig. 11.10 Anorexia Girl

Prevention and Treatment: Gradual reduction in the food, regular exercise also increase metabolic rate.

Related Disorders: Obesity is also the cause of diabetes mellitus, cardiovascular disease and stroke, angina, heart failure, arthritis and anemia, obesity shortens life span.

13.3.4 Anorexia Nervosa

(Gk. An; with out: orexic: longing; intense desire; Nervosa: nervous)

It is the loss of natural strong desire towards food due to the fear of becoming obese. Such a feeling is common in female between the ages of 12 to 21 years.

Symptoms: Loss of appetite, anorexic girl over estimate the size of her own body. They do not mature psychologically and are unable to face the challenges of puberty and emerging sexuality. The patient is mostly emotionally disturbed in making new friends or maturing sexual relation. The patient may be seen engaged in prolonged exercises.

They loss feminine (women) characteristics and the girls retreat (retire) into childlike state in which she feels safe.

Treatment: Psychiatric therapy is usually required to treat anorexia girls. They are fed through other route than alimentary canal i.e, intramuscularly or intravenously. The recovery of anorexia is very slow. It may take 2 to 4 years or more. Group and family therapy is applied to reduce depression.

11.3.5 Bulimia Nervosa: (Gk. Bulimia; bous, ox, limous, hunger) (Nervosa; nervous)

It is a neurotic disorder in older girls.

Symptoms and cause: Bouts (a spell) of excessive eating of fattening food of high calories followed by self-induced vomiting, fasting or purgatives i.e., making stomach empty with a laxative. This frequent vomiting and purging (purify) may cause physical effects including serum electrolytes imbalance and frequent recurring infections.

> **For your Information**
>
> *Giardiasis is a disease of small intestine caused by giardia. It is most common pathogenic parasite of human gastro-intestinal tract.*

They develop ulcer due to regular use of laxatives.

Damage tooth enamel from acids in digestive fluids of vomits.

Treatment: the initial treatment of bulimics is to overcome the effects of weight loss and malnutrition, family therapy: antidepressant drugs can also be used. The patient should be admitted in hospital and treated under strict supervision.

11.3.6 Piles (Hemorrhoids)

Symptoms: painful masses of dilated, tortuous (full of twist and turns) and swollen vein in the anorectal (anus + rectum) mucosa. It causes itching and may bleed during bowl movement.

> **Can you guess?**
>
> *What is peptic ulcer and what are its causes?*

Causes:

- It may include prolonged constipation.
- During pregnancy.
- Liver disorder and gas of stomach and intestine.
- Fatty diet which cause gas.

Treatment:

- Improvement of the hygienic conditions .
- Use of food softeners such as roughage in food or laxative to prevent from constipation.
- The patients should not sit on hard seats.
- Hemorrhoids are also removed by surgery.

Activity

Stomach ulcer, food poisoning and dypepsia are common digestive system disorders of our society. Make a list of main causes of these disorders and their preventions through your personal observations and by searching different reliable sources.

11.3.7 Ulcer

The sore (pain) in the stomach and duodenum is called ulcer or peptic ulcer. It is more in man than women.

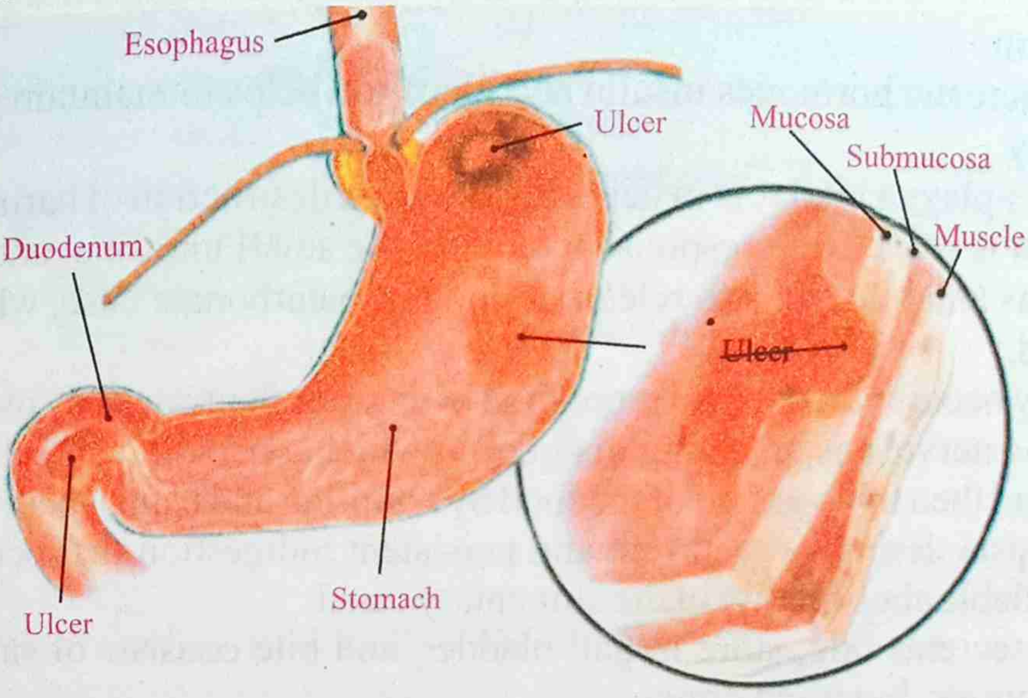


Fig. 11.10 Peptic Ulcer

Causes (Aetiology):

Break down of inner mucous layer of gastrointestinal tract by combine action of pepsin and HCI in the stomach cause peptic ulcer. Excessive alcohols. Stress, aspirin and anxiety (mentally troubled).

Helicobacter pylori bacterium is the most important factor in peptic ulcer.

Prevention and Treatment:

The patient should avoid spicy food and use simple food. Avoid excessive intake of tea and coffee.

The patient should also avoid from alcohol and smoking. Missing of meal are to be avoided. Antacids like milk and other drugs such as **cimetidine** reduce gastric secretions and help in healing ulcer. Sedative drugs help to reduce stress and tension. Vomiting relieves pain in gastric ulcer.

SUMMARY

- Digestion is the process by which polymers, large and complex food is broken

EXERCISE

Section - I: Objective Questions.

Multiple Choice Questions

Select the best option.

1. The teeth adapted for tearing are called .
   (a) Incisor (b) Canine
   (c) Molar (d) Premolar
2. The opening from the oesophagous into stomach is called.
   (a) Cardiac opening (b) Pyloric opening
   (c) Stomach opening (d) Oesophagous opening

3. Which of the following enzyme is secreted by gastric gland?
(a) Amylase (b) Lipase
(c) Pepsin (d) Trypsin

4. Excess intake of carbohydrate causes.
(a) Obesity (b) Piles
(c) Dyspepsia (d) Bulimia nervosa

5. Fatty acid and glycerol are first absorbed by.
(a) Lymph vessel (b) Villi
(c) Capillaries (d) None of these

6. *Helicobacter pylori* causes
(a) Peptic ulcer (b) Piles
(c) Bulimia (d) Anorexia

7. Bile is the secretion of
(a) Pancreas (b) Liver
(c) Stomach (d) Intestine

8. Stomach consists of ________ parts
(a) 5 (b) 4
(c) 3 (d) 2

B. **Fill in the blanks.**

1. The premolars and molars are specialized for _____.
2. The enzyme present in salvia is called __________.
3. The oesophagous is about __________ long.
4. The outer most opening of stomach is called _____.
5. Lipase is a __________ digesting enzyme.
6. Chyme is turned into a watery emulsion called____.
7. Secretin is hormone produced by ______________.
8. The bilirubin is produced by the breakdown of____ in liver.
9. *Salmonella* is a bacterium cause disease __________.
10. The enzyme trypsinogen is changed into trypsin by_______.

neither

10.3 Transport in Plants

The movement of materials into the body, within the body and out of the body of the organism is called transport. In plants the examples of transport are absorption of water and minerals from the soil through roots and the movement of organic solutes from leaves to different parts of the plants.

10.3.1 Movement of water between plant cells and their environment

The movement of water between plant cells and their environment takes place by osmosis. **Osmosis** is the movement of water from a region of higher water concentration towards lower water concentration through a semipermeable membrane. The absorption of water from soil to roots is example of osmosis in plants. If water moves into the cell by osmosis then it is called endosmosis and if water moves out of the cell then it is called exosmosis.

Water relations of the cells:

On the basis of movement of water into and out of cell, there are three kinds of water relations, i.e., water potential, solute potential and pressure potential.

Water potential:

The total kinetic energy of water molecules due to which they move from place to place is called water potential. The greater concentration of water molecules in a system, the greater is the kinetic energy of water molecules. The potential is denoted by a Greek symbol Ψ (Psi), so water potential is denoted by Ψw. The Potential is expressed in the unit of pressure called Pascal (Pa).

Two factors determine the water potential in plants:

i) Solute concentration, i.e., osmotic potential of solute (Ψs)

ii) Pressure polential (Ψp) so $\Psi w = \Psi s + \Psi p$

Pure water has maximum water potential. Thus water potential is zero. By definition water molecules always move from a region of higher water potential to a region of lower water potential.

> **Critical Thinking**
>
> *Do you know why we usually water plants in the morning or evening but not in the afternoon?*

Applications of water potential:

There are following applications of water potential.

i) Water potential can be used to measure the tendency of water to move between any two systems.

ii) Water potential can also be used for movement of water from soil to roots, from leaf to air, from air to soil.

The following example will help to understand the concept of water potential. Two adjacent vacuolated cells are shown with Ψw, Ψp, Ψs. The kPa = 1000 pascal.

Example

Cell A		Cell B	
Ψw	= -1400 kPa	Ψw	= -600 kPa
Ψs	= 600 kPa	Ψs	= 800 kPa
Ψp	= -2000 kPa	Ψp	= -1400 kPa

Qusestions

- Which cell has higher water potential?
- In which direction will water move by osmosis?

- What will be the water potential of the cell at equilibrium?
- What will be the solute potential and pressure potential of the cell at equilibrium?

Solute potential: (Osmotic potential):

The change in water potential of a system due to addition of solute is called osmotic potential or solute potential. **Solute potential** is always negative, i.e., with increase in solute the osmotic pressure will also increase. **Osmotic pressure** is an important factor affecting cells. In hypotonic solution the cell gets swell, in hypertonic solution the cell gets shrink while in isotonic solution the cells retain their shape and size.

Pressure potential (Ψp):

The pressure exerted by the protoplast against the cell wall of plant cell is called pressure potential. Water potential increases when pressure greater than atmospheric pressure is applied on pure water solution. It is equivalent to pumping water from one plant to another. Such situation may arise when in living cells the water enters into plant cell by osmosis. This water builds up pressure inside the cell and make the cell turgid. It also increases the pressure potential. The pressure potential helps to maintain the shape of the cell.

10.3.2 Uptake of Water by Roots and Pathways

The root hairs are located on the edge of the roots while xylem vessels are in the center. Before the water can be taken to the rest of the plant, it must reach to xylem vessels through root hairs. There are following three pathways taken by water to reach the xylem vessels.

a. Apoplast pathway
b. Symplast pathway
c. Vacuolar pathway

Apoplast pathway:

The movement of water through the extra cellular pathway between the cell walls of adjacent cells is called apoplast pathway. The ions easily reach the endodermis by this

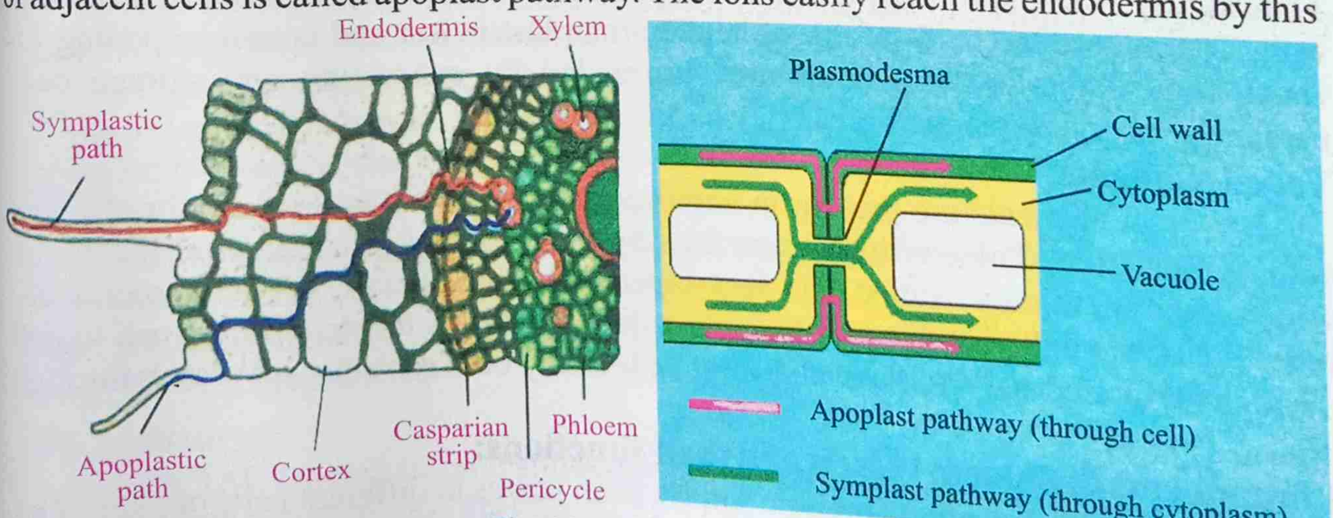


Fig. 10.3 Pathway of water

pathway, but the **casparian strips** prevent further movement. The casparian strip is a band of cell wall material deposited in the radial and transverse walls of root endodermal cells. It is chemically composed of suberin (a water proof waxy substance). Thus these ions must enter into the endodermal cells by diffusion or active transport. They enter into cytoplasm or vacuole of the endodermal cells.

Symplast pathway: The movement of cell sap through the plasmodesmata of cell is called symplast pathway. **Plasmodesmata** (singular plasmodesma) are cytoplasmic microscopic channels between cell walls of adjacent plant cells which enables transport and communication between them. There is a concentration gradient down the cells of cortex, endodermis, pericycle and sap of xylem so minerals move down through plasmodesmata into the cells of cortex, endodermis, pericycle and then to the sap of xylem.

The vacuolar pathway: The movement of water molecules in plant cells via the vacuoles located in the cytoplasm of the cell. The water molecules encounter high resistance and as a result little flow usually occurs, making this pathway less efficient than apoplast and symplast pathway. Water moves by osmosis across the vacuoles of the cells of root system.

10.3.3 Structure and Function of Xylem and Phloem

Xylem and phloem are two types of transport tissues in vascular plants. The basic function of xylem is to transport water from roots to shoots and leaves but also transport some nutrients. The phloem transports organic food from photosynthetic cells to all parts of plants for use and storage.

Components of xylem: The word xylem is derived from the Greek word *"xylon"* meaning wood. These are elongated cells and tubular water transport system because these cells are connected end to end with each other. There are two main kinds of cells in xylem, i.e. Tracheids and Vessel elements.

Tracheids: Tracheids are elongated cells up to 80 nm wide with secondary lignified cell wall. The mature tracheids are dead hence protoplast is lost and creating opening for water flow. Functional tracheids are surrounded by supporting and storage cells paraenchyma, sclereids and fibres.

Vessel elements:

Vessel elements are present in angiosperms. These are specialized for efficient water conduction. These reduce water loss by transpiration. The vessel elements are wider, shorter, thinner walled and less tapered than tracheids. Vessel elements are individual cells linked end to end froming xylem vessel. Water stream from cell to cell through perforated end walls and also migrate laterally between adjacent vessels through pits.

Components of phloem vessels and their functions:

The phloem transports organic solutes from leaves to different parts of plant. The phloem tissue is present on outside of xylem tissue. The phloem is a permanent tissue that

is composed of three living cells and one dead cell. The living cells are sieve tube elements, companion cells and the phloem parenchyma while the dead cell is sieve tube. The **sieve tube** are long elongated cells placed end to end with the walls composed of cellulose. The end walls of sieve tubes are perforated. The perforated area looks like a sieve thus known as sieve plate. These pores of sieve tube help in translocation of solutes. The **companion** cells are thin walled elongated cells associated with sieve tube. These are living cells containing cytoplasm and elongated nucleus. The companion cell and sieve tube are in communication with each other through plasmodesmata. The companion cells provide energy to sieve tubes. The phloem tissue also possesses parenchyma that has storage function and very thick walled fiber cells which provide support.

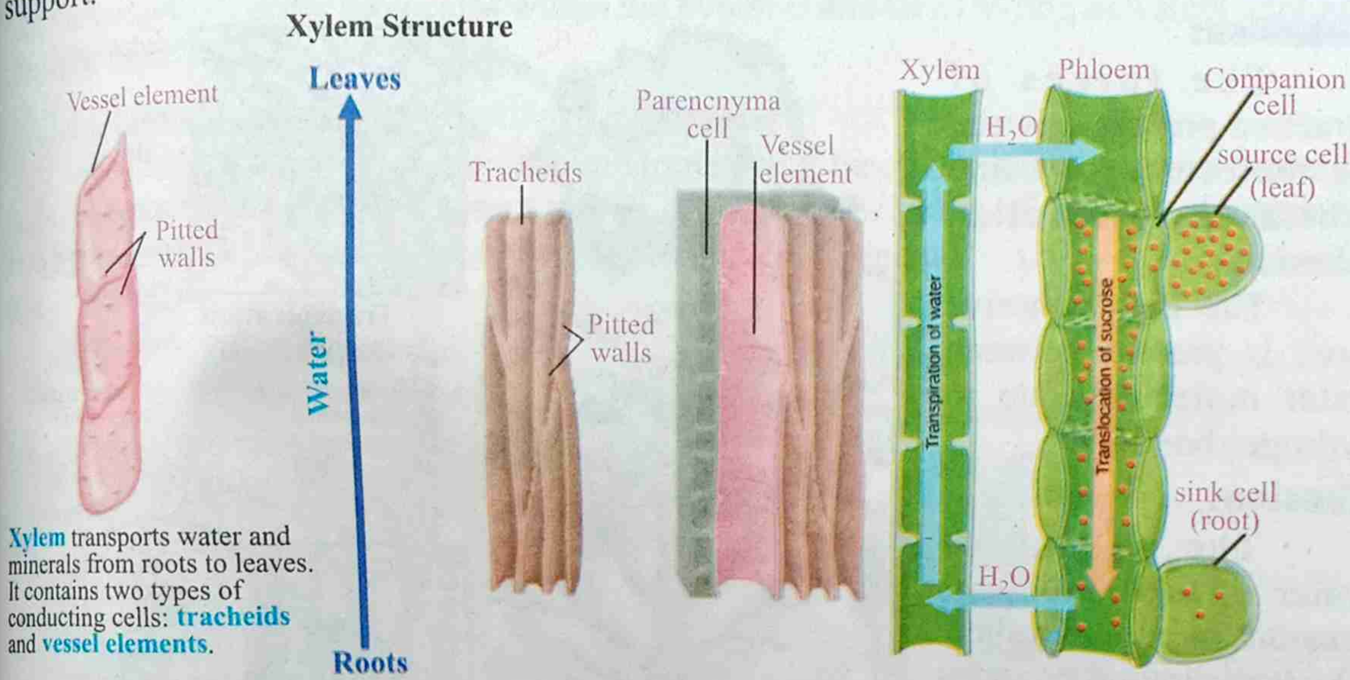


Fig.10.4 Structure of Xylem and phloem

10.3.4 Ascent of sap

The pull of water and dissolved minerals through the xylem tissue towards the leaves is known as ascent of sap. The water and dissolved minerals are collectively called sap and ascent means upward movement. Dissolved minerals from soil enter in root hairs and then move through the following path ways:

Epidermis ⟶ cortex ⟶ endodermis ⟶ pericycle ⟶ xylem ⟶ leaves

As the ascent of sap is against the gravity, therefore, a considerable force is required to transport the sap especially in tall plants. The sap is transported from roots to leaves through xylem by TACT forces. These TACT forces also known as TACT theory, responsible for ascent of sap.

TACT theory:

The TACT stands for Transpiration pull, Adhesion, Cohesion, Tension. The ascent of sap through "these forces" are called TACT theory.

Transpiration pull:

The transpiration involves in the pulling of water upward by utilizing the energy of evaporation. Transpiration pulls the water at much higher speed (upto 8 m/h). About 99% of pulled water is transpired while remaining 1% is used for various activities like photosynthesis.

Adhesion:

The force of attraction between the water molecules and other substances is called adhesion. The water and cellulose are polar molecules, therefore, strong attractive forces are present between water and cellulose, so the water molecules adhered to xylem tissue and column of water does not break.

Cohesion:

The forces of attraction present between the molecules of same substances are called cohesion.

The high cohesive force is present between water molecules due to hydrogen bonding.

Tension:

The pulling of water upward produces tension in xylem tubes. The transpiration provides the necessary energy. The hydrogen bonds between water molecules produce this tension. In xylem water tension is much stronger. It can pull the water upto 200 m (more than 600 feet) in plants.

Mechanism of TACT force:

The evaporation of water from the aerial parts of plants especially through stomata of leaves is called **transpiration.**

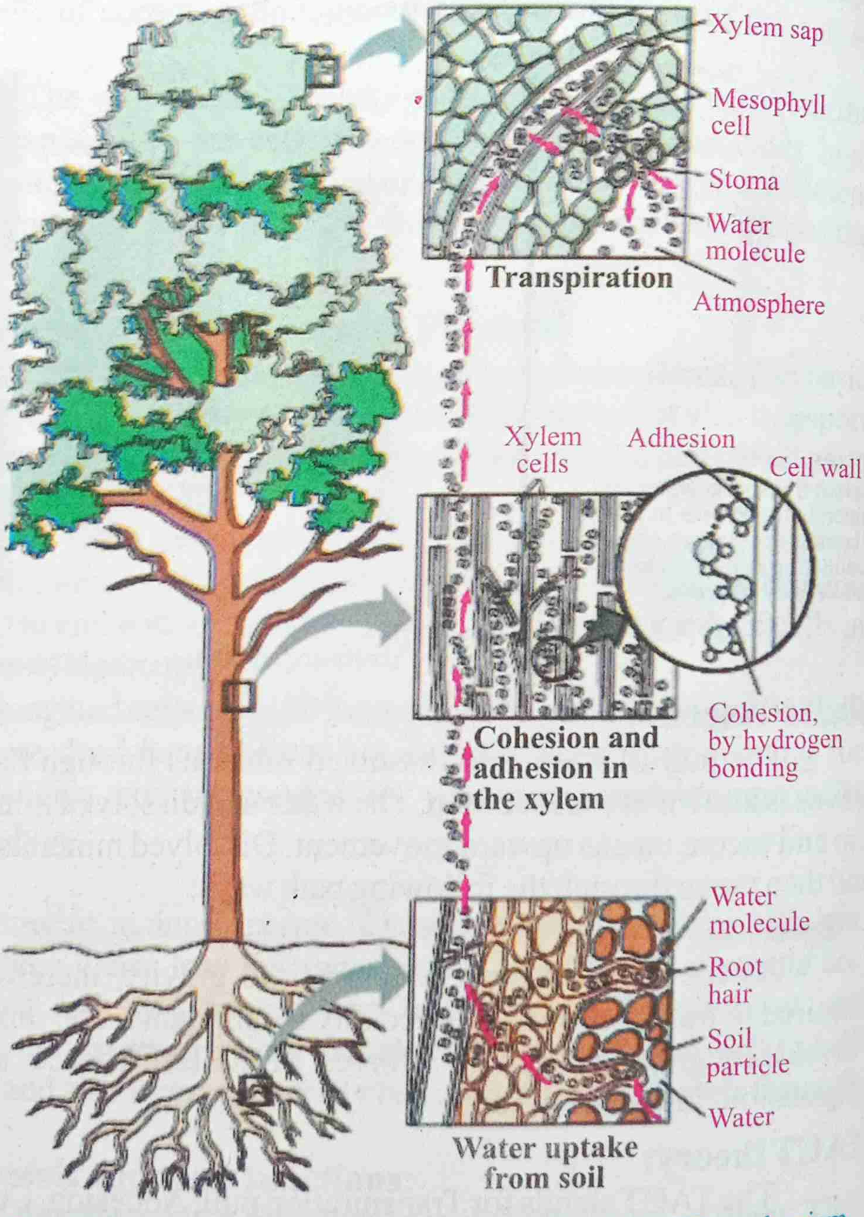


Fig. 10.5 Movement of water in xylem through TACT mechanism

Due to transpiration water potential of mesophyll cells drops which causes water to move by osmosis from xylem cells of leaf into dehydrating mesophyll cells. The water molecules leaving the xylem are attached to other water molecules in the same xylem tube by hydrogen bonds (cohesion of water molecules), therefore, when one water molecule moves in the xylem, the process continues all the way to the roots where water is pulled from xylem.

Tit bits

The combination of adhesion. cohesion and surface tension allow water to climb upward. It is called capillary action.

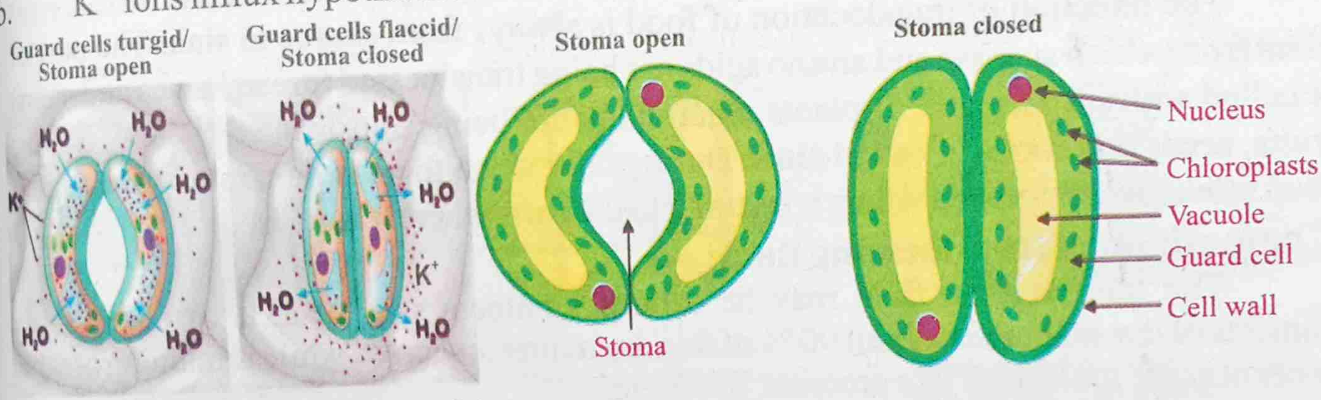
This pull also causes water to move down its concentration gradient transversely from root epidermis (root hairs) to the cortex endodermis and to pericycle. It is estimated that the column of water molecules within the xylem is atleast as strong as a steel wire of the same diameter.

10.3.5 Opening and closing of stomata

As discussed earlier in this chapter stomata are the openings between two guard cells. The guard cells play important role in opening and closing of stomata. There are two hypothesis for explaining the opening and closing of stomata.

a. Starch sugar hypothesis.

b. K^+ ions influx hypothesis.



(b) Role of potassium in stomatal opening and closing

Fig. 10.6 Opening and closing of stomata.

a. Starch sugar hypothesis:

This hypothesis was proposed by German botanist Hugo von Mohl. According to this hypothesis the guard cells are the only photosynthesizing cells of leaf epidermis because they have high contents of chlorophyll than the surrounding epidermal cells.

Opening of stomata: Photosynthesis takes place during day time so sugar is produced in the guard cells during day time. The increase in sugar level increases the solute concentration in the cell. Therefore, water potential in the cell decreases. As a result the guard cells absorb water and become turgid and curved. This creates an opening in stoma.

Closing of stomata: The process of photosynthesis slows down at night. The already present sugar is utilized in respiration or stored in the form of insoluble starch. So the

osmotic potential of guard cells is higher. Thus water leaves the guard cells, they become flaccid and stomata are closed.

b. K^+ ions influx hypothesis:

According to this hypothesis when photosynthesis starts in morning, this causes a decrease in level of CO_2 in guard cells. The low level of CO_2 stimulates the inward movement of K^+ ions into the guard cells.

Opening of stomata: The accumulation of K^+ ions in guard cells decreases the osmotic potential so water enters the guard cells by osmosis. As a result guard cells become more turgid so stomata are opened.

Closing of stomata: The stomata close by reverse process. There is a passive diffusion of K^+ ions from guard cells to outside so water also moves out by osmosis. The guard cells become flaccid and close the stomata. The level of CO_2 in the space inside the leaf and light control the movement of K^+ ions into and out of guard cells.

10.3.6 Translocation of organic solutes

The movement of sucrose and amino acids in phloem, from region of production to region of storage or to regions of utilization is called translocation of organic solutes.

Pattern or direction of translocation:

The direction of translocation of food is always from source to sink. The part of plant from which sucrose and amino acids are being translocated (green leaves and stem) is called **source.** The part of plants where they are being translocated (yellow leaves, fruits, seeds and roots) is called **sink.** During cold when there is no photosynthesis, the food moves from the parts where it is stored to the parts where it is utilized.

Composition of translocating fluid:

The translocating fluid may be called as phloem sap. 10-25% of phloem sap consists of dry matter and about 90 % of this dry matter is sucrose while remaining are the other organic molecules like proteins, lipids etc.

Mechanism of translocation:

There are different views about the mechanism of translocation but most acceptable one is pressure flow or mass flow theory.

Pressure flow theory:

Ernst Munch proposed a hypothesis in 1927 to explain the mechanism of translocation. This hypothesis states that an osmotically generated pressure gradient between source and sink drives the solution through the sieve elements. Now this hypothesis has been given the status of theory. The pressure flow theory accounts for the mass movement of molecules within phloem. It may be noted that carbohydrates from the mesophyll cell to phloem tissue involve diffusion and active transport. Then in phloem tissue the movement of materials takes place in bulk and according to the pressure flow mechanism.

Introduction

All living cells require efficient supply of nutrients, oxygen, hormones etc. The cells must get rid of metabolic wastes like CO_2 and nitrogenous wastes. Small organisms meet their requirements of supply of nutrients and oxygen and removal of waste products, simply by means of diffusion. Tiny animals have small size and large surface area so this process of diffusion is sufficient to meet their required transport of substances.

The larger and active animals like human cannot rely on diffusion alone. Therefore these animals must need an efficient transport system.

This chapter deals with human transport system and its components i.e., Heart, blood, blood vessels and blood pressure and cardiovascular disorders.

> **Tit bits**
>
> *The study of diseases of cardiovascular system is called angiology.*

12.1 Blood Circulatory System of Man

Human blood circulatory system is composed of following parts i.e., a muscular pumping organ called heart, a system of interconnecting tubes called blood vessels and a circulatory fluid, the blood. The blood always remains in the vessels so the system is known as closed circulatory system.

12.2 Human Heart

The heart of an adult human has a mass of around 300 grams, and is about the size of our fist. It is the most powerful organ in the circulatory system. The heart lies in the thoracic cavity between the lungs, slightly towards left, enclosed within the rib cage, with the sternum in front and vertebral column behind. It is surrounded by a double layered **pericardium.** A pericardial fluid is secreted in between these two layers. It lubricates and reduces the friction between the heart walls and surrounding tissues during the beating of heart.

> **Do you know?**
>
> *Dr. Christen Barnard carried out the first heart transplant in 1967. The recipient, Louis Washkansky only lived for 18 days after transplant but now most of heart transplant patients are expected to survive for the rest of their life.*

> **Tit bits**
>
> *Cardio-logy from Greek Kardia, "Heart" and logia "study" is a branch of medicine dealing with disorders of heart as well as parts of circulatory system.*

Structure of Human Heart

The heart is conical in shape and dark red in colour. The heart has four chambers, a **left and right atrium** at the top, and a **left and right ventricle** beneath. The right side is completely separated from the left side by a **septum.** The walls of heart are made almost entirely of a special kind of muscles called cardiac muscles. It is the regular contraction and relaxation of these muscles which produces the pumping movement of the heart called **heart beat**.

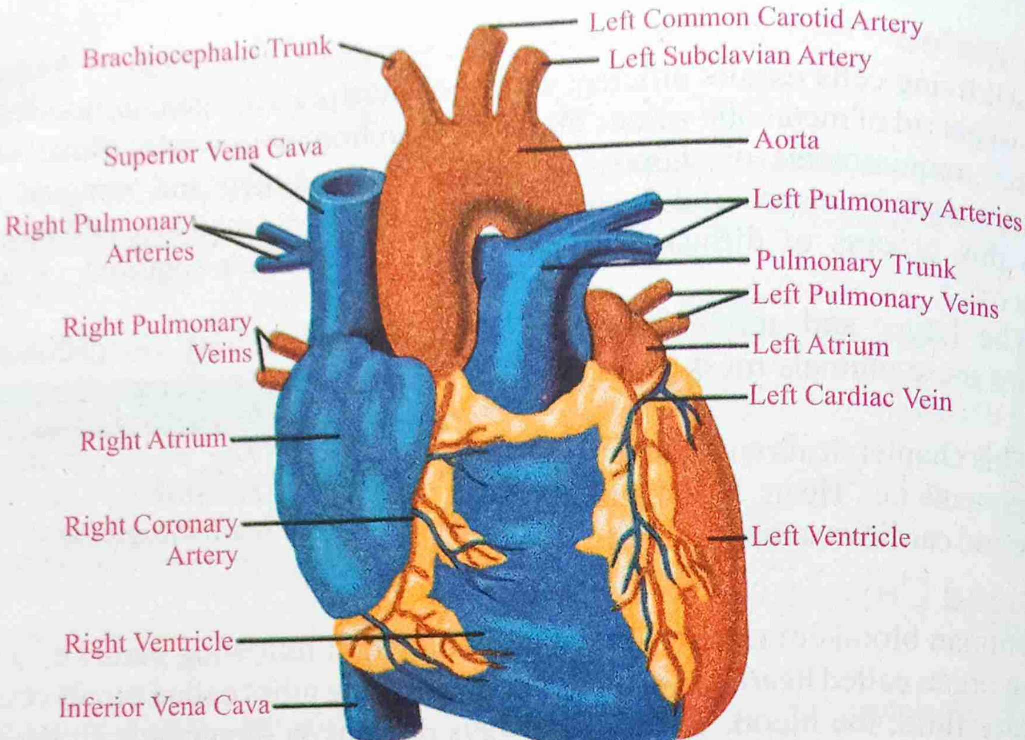


Fig. 12.1 External Structure of Heart

The **atria** on each side of the heart are separated from the **ventricles** by valves. These are atrioventricular valves (AV valves). The one on the left is often known as

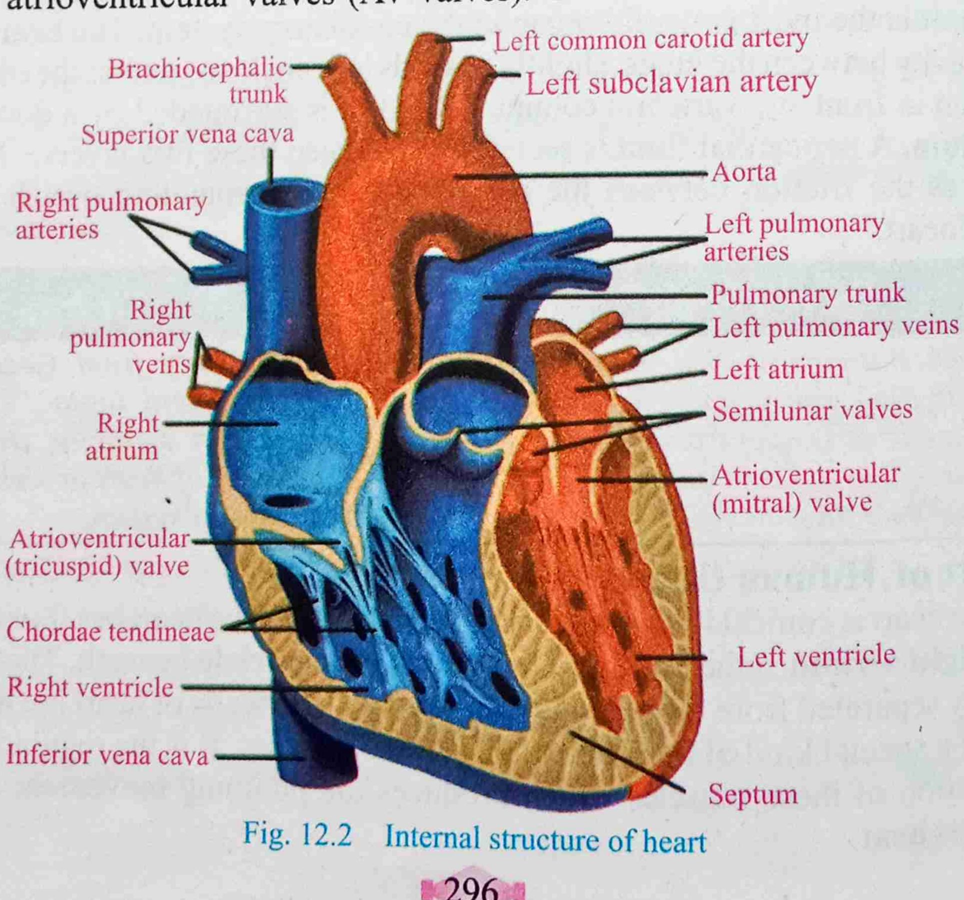


Fig. 12.2 Internal structure of heart

mitral valve, or alternatively the **bicuspid valve** because it has two flaps. The one on the right side is called **tricuspid valve.** The valves control one way flow of blood i.e. from atria to ventricles but prevent back ward flow.

The **semilunar valves** guard the emergence of pulmonary arch and systemic aorta. These valves also prevent backward flow of blood. On the outside of heart blood vessels can be seen. These are called **coronary arteries** which deliver oxygenated blood itself to the heart walls.

The heart wall is formed of three layers:

Epicardium: outer most, **Myocardium**, middle, **endocardium**, innermost. The epicardium is thin and comprising of smooth outer surface of heart. The myocardium is thick and composed of cardiac muscle cells. The endocardium consists of simple squamous epithelium.

> **Tit bits**
>
> *Heart block is a disease or inherited condition that causes a fault within the natural pace maker of the heart, due to some kind of obstruction or block in the electrical conduction system of heart.*

12.2.1 Heart Beat and its Control (cardiac cycle)

Adult human heart beats around 72 times per minute. One heart beat is called cardiac cycle. A cardiac cycle is a sequence of events which takes place in the heart during one heartbeat. First the atria contract; this is called **atrial systole**. As a result of this contraction blood is forced into the ventricles through atrio-ventricular valve now the ventricles contracts. This stage is called **ventricular systole.** The walls of ventricles are thicker and stronger than atrial walls, so they can produce much greater force. The blood is squeezed up into the aorta from the left ventricle and the pulmonary artery arises from the right ventricle. The

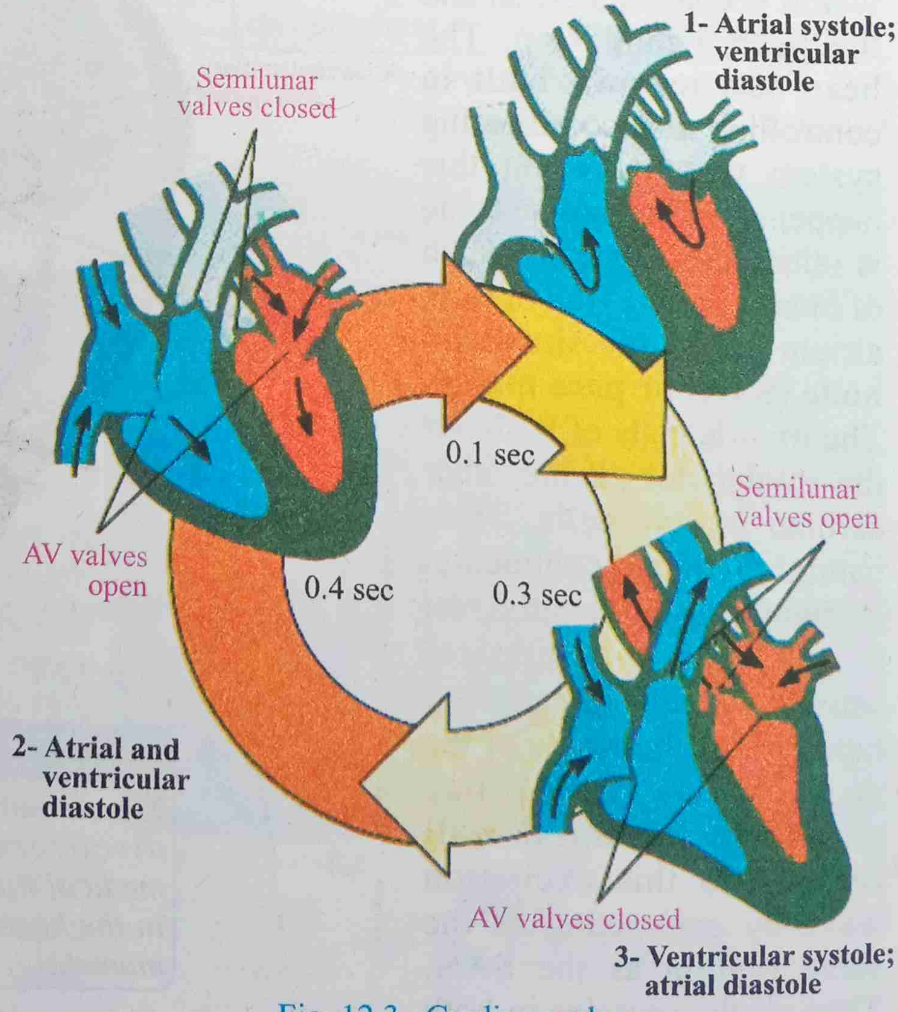


Fig. 12.3 Cardiac cycle

pressure of the blood in the ventricles pushes upward on the atrioventricular valves, pushing them shut. So if the valves are working properly no blood can go backwards into the atria. Next the muscles in the atria and ventricles relax. This is called **diastole.**

> **Do you know?**
>
> ***Cardiac output:*** *The volume of blood leaving the left ventricle is known as stroke volume.*
>
> *Cardiac output is the volume of blood leaving the left ventricle per minute so cardiac output = stroke volume x heart rate.*

12.2.2 Conducting System of the Heart

The cardiac muscles are **myogenic.** This means that these muscles contract and relax naturally. Heart does not need to receive impulses from a nerve to make it contract. If heart is kept in warm oxygenated solution containing nutrient's, the heart muscles will contract and relax rhythmically by themselves. However the individual heart muscle cells can not be allowed to contract at their own natural rhythms because if so the part of heart would contract out of sequence with other parts, the cardiac cycle would become abnormal and the heart would stop. The heart has its own built in controlling and coordinating system which prevent this happening. The cardiac cycle is initiated in a special patch of muscles in the wall of right atrium called the **sinoatrial node (SAN) or pace maker.** The muscle cells of SAN set the rhythm for all the other cardiac muscle cells. Their natural rhythm of contraction is slightly faster than the rest of the heart's electrical activity, which spreads out rapidly over the whole of the atrial walls. The cardiac muscle in the atrial wall respond to this excitation wave by contracting as the same rhythm as the SAN. Thus all the muscles in both

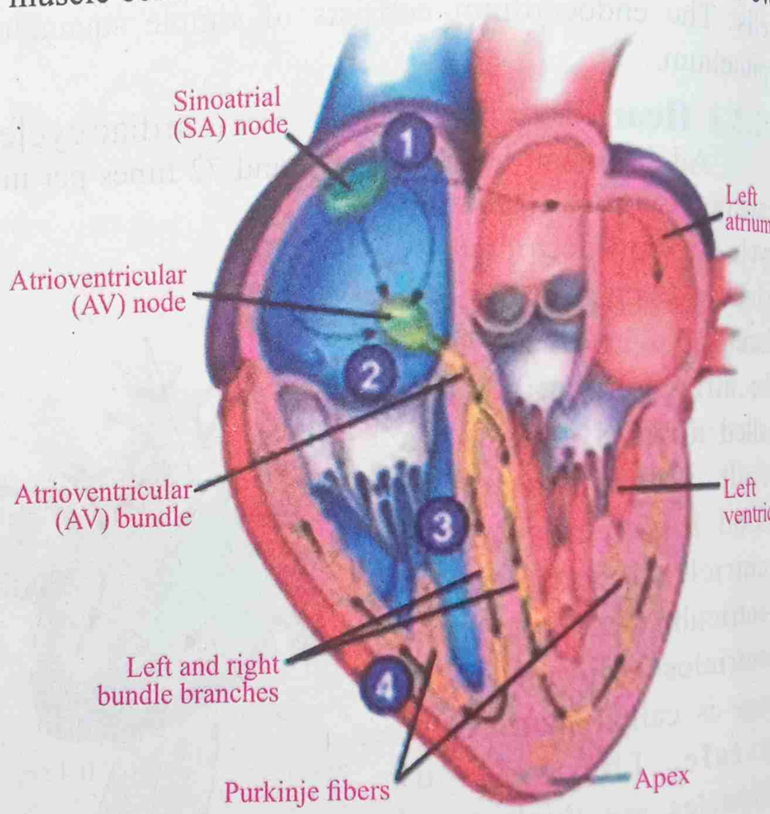


Fig. 12.4 SA node AV node

> **Tit bits**
>
> *The sinoatrial node was first discovered by a young medical student Martin Flack in the heart of mole, A small mammal.*

atria contract almost simultaneously.

As we know the muscles of ventricles do not contract until after the muscle of atria contract. This delay is caused by a feature of heart that briefly delays the excitation waves in its passage from atria to ventricles.

There is a band of fibers between the atria and ventricles which does not conduct the excitation wave. Thus as the wave spread out from the SAN over the atrial walls, it cannot pass into the ventricle walls. The only route is a patch of conducting fibers situated in the septum, known as atrio-ventricular node (AVN). The AVN picks up the excitation wave as it spreads across the atria. Besides, there is a bundle of nerve fibers called atrioventricular bundle (AV) or "Bundle of His" arising from AV Node, it pass through the septum in between the ventricles and divides into right and left bundle branches. Numerous conducting fibers called "Purkinje Fibres" arise from the branches and spread over the ventricles.

12.2.3 Electrocardiogram

The electrocardiogram (ECG) also known as EKG. It is a non invasive device that measures and records the electric activity of the heart over a period of time using electrodes placed on the skin. These electrodes detect the tiny electrical changes on the skin that arise from the heart muscles that is electrophysiological pattern of depolarization and repolarization during each heartbeat.

Tit bits

An elctrocardiograph is a machine that is used to perform electrocardiography and produces the electrocardiogram.

The first part of the wave called "P" wave is a small increase in the voltage of about 0.1 mV that corresponds to the depolarization of the atrial systole. The next part of ECG is the "QRS" complex which features a small drop in voltage (Q) a large voltage peak (R) and other small drop in voltage (S). The "QRS" complex corresponds to the depolarization of the ventricle during ventricle systole. The atria also repolarize during the "QRS" complex but have almost no effect on the ECG because they are quite smaller than ventriclular waves.

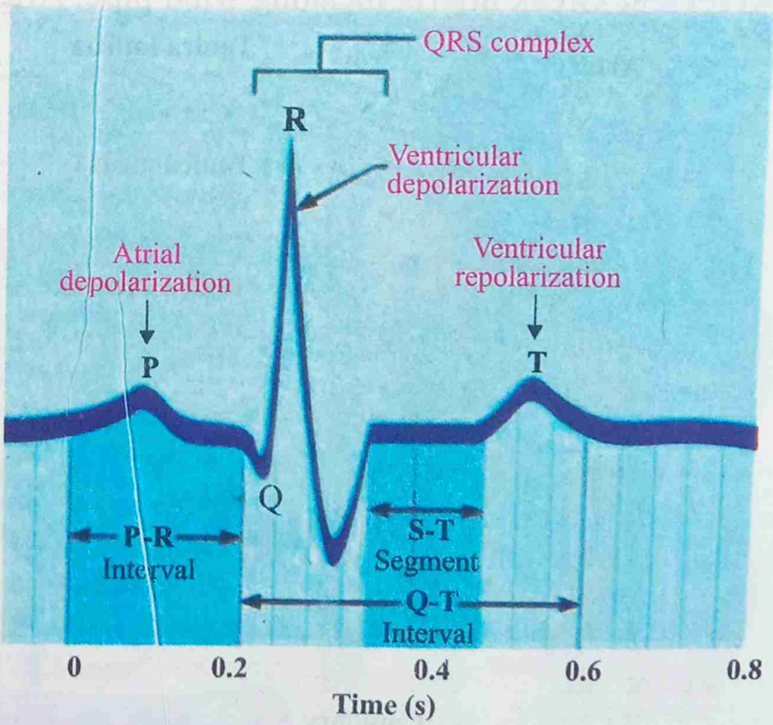


Fig. 12.5 ECG

The final part of ECG wave is the "T" wave, a small peak that allows the QRS complex occurs just prior to ventricular contraction. The "T" wave represents the ventricle repolarization during the relaxation phase of the cardiac cycle.

The overall goal of performing electrocardiography is to obtain information about the function of heart e.g., suspected myocardial infarction, suspected embolism, increase in size of heart, to access the severity of electrolytes abnormalities etc.

> **Do you know?**
> *Sinus bradycardia is a sinus rhythm with a rate that is lower than normal. In humans bradycardia is generally defined to be a rate of under 60 beat per minute, while sinus tachycardia is a sinus rhythm with a elevated rate of impulses usually greater than 100 per minute.*

12.3 Blood Vessels

There are three major types of blood vessels i.e. arteries, veins and capillaries. **Arteries** always carry blood away from heart. All arteries carry oxygenated except pulmonary arteries. The largest artery **(aorta)** divides into smaller one and these continue to divide to form much smaller vessels called **arterioles**. These in turn divide further into smaller vessels called **capillaries.** These capillaries then join up with each other to form **venule** and these finally merge to form **veins.** These bring the blood back to heart. All veins bring deoxygenated blood except pulmonary veins. Veins unite to form venae cavae.

> **Tit bits**
> *The aorta is the largest artery while vena cava is the largest vein in the body.*

Arteries: Greek arteria meaning wind pipe. Arteries are

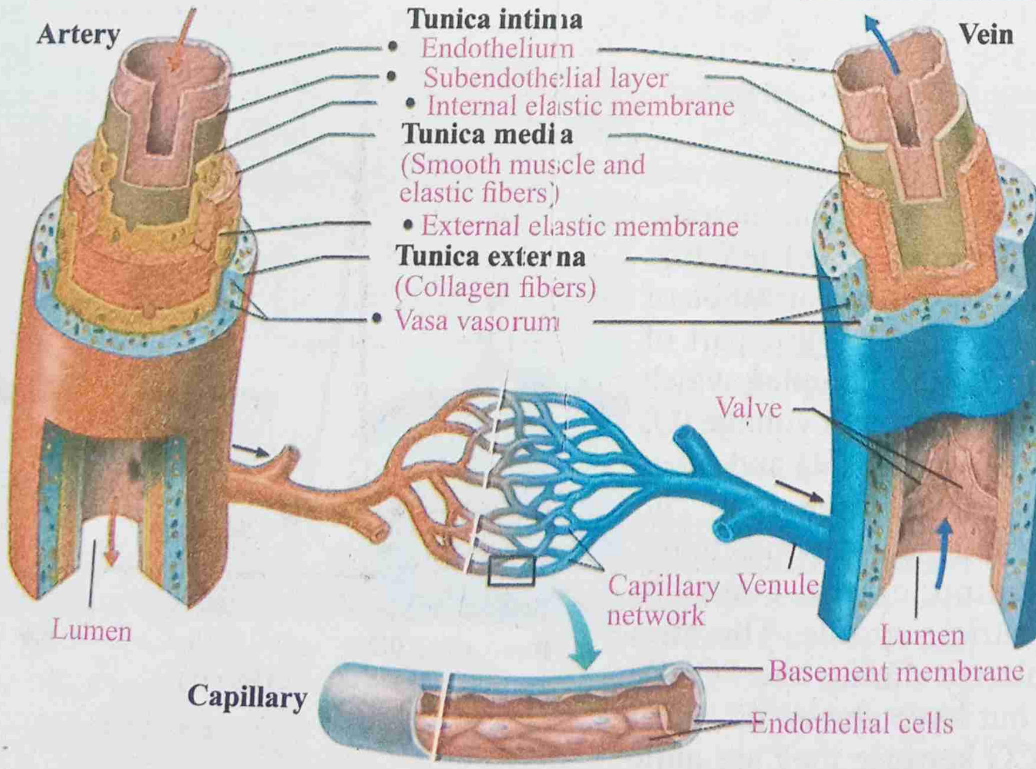


Fig. 12.6 Blood Vessels

thick walled vessels consisting of three layers. The outer layer of an artery is known as **tunica externa** and is composed of connective tissues made up of collagen fibers. Inside this layer is **tunica media** which is made up of smooth muscle cells and elastic tissue. The innermost layer which is in direct contact with the flow of blood, is the **tunica intima.** This layer is made up of epithelial cells.

Capillaries: These are the smallest and thinnest of blood vessels in the body. The intimate relationship between the circulatory system and the tissues is achieved at the level of capillaries. The function of capillaries is to carry blood as close as possible to all cells allowing rapid transfer of substances between cells of the body. Human capillary is approximately 7 to 9 μm in diameter almost same size as a red blood cells, which can, therefore, only pass along the capillary in single file. Moreover the walls of capillaries are extremely thin, made up of a single layer of endothelial cells. This thinness of capillary walls helps to speed up the exchange rate of materials with the tissues.

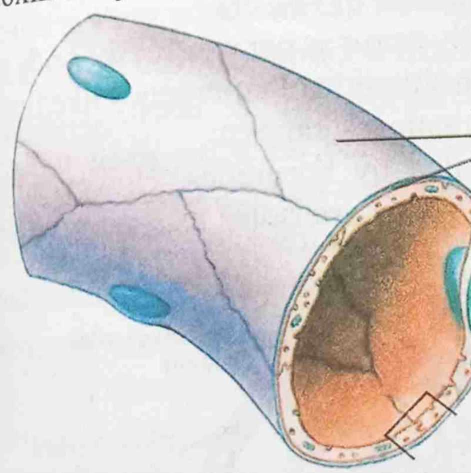


Fig. 12.7 Capillary

Veins: Veins are the blood vessels that bring blood back towards heart. Most veins carry deoxygenated blood except the pulmonary and umbilical veins. Veins are less thick and less elastic than arteries. Moreover veins have relatively larger lumens than arteries.

A vein consist of three main layers. The outer thicker layer made up of connective tissue called the tunica externa or tunica adventitia. The middle layer is called tunica media and is composed of smooth muscle. This layer is quite thinner than arteries. The inner most layer is called tunica intima.

Tit bits

Cornea and cartilage lack capillaries. Therefore these structures are slow to heal if injured.

Tit bits

Veins are called capacitance vessels because most of blood volume (60%) is contained with in veins.

Tit bits

The veins appear blue because the subcutaneous fat absorb low frequency of light and reflect blue light.
Cardiac veins: *The vessels that remove deoxygenated blood from the heart muscles.*

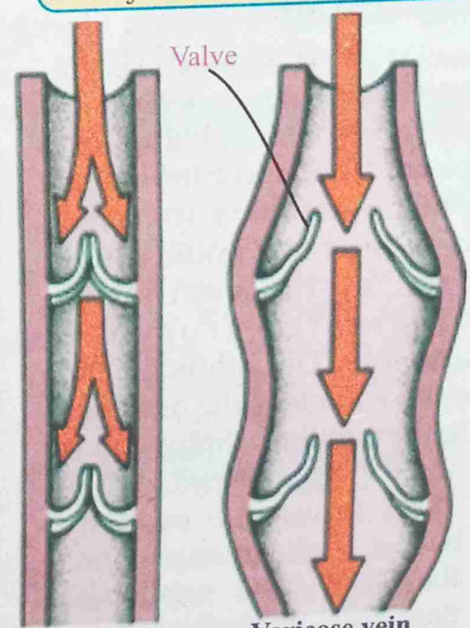


Fig. 12.8

The largest vein in human body is vena cava which enters the right atrium of heart from above and below.

The venules are small veins that collect blood from capillaries which then drai into veins.

Valves in veins: Veins mostly contain valves which prevent back-ward flow of bloo These valves are present in larger veins having diameter greater than 2mm. Howeve these valves are needed only in lower part of the body such as veins of hind limbs an abdomen, without these valves the flow of blood towards heart is very slow and difficult.

12.3.1 Role of arterioles in vasodilation and vasoconstriction

Vasodilation means widening of blood vessels as a result, blood flow increase due to decrease in vascular resistance (Due to increase of diameter of vessel.)

Vasoconstriction is the narrowing of blood vessels to decrease, blood flow due to increase in vascular resistance (Due to decrease in diameter of vessel).

The vasoconstriction and vasodilation normally occur as per need of the body e.g. to regulate body temperature during hot and cold or in situation of emergency like flow of blood from injury or during emotional situations e.g., sadness, rage etc.

Vasodilation and vasoconstriction is controlled by hormones. However thick smooth muscle layer in arterioles make this possible. The arterioles usually have large number of smooth muscles to perform this task.

12.3.2 Role of Pre-capillary sphincter in regulating the flow of blood through capillaries

A pre-capillary sphincter is a band of smooth muscle that adjust blood flow into capillaries. The pre capillary sphincter is located at a point where each of the capillaries originates from the arteriole. The sphincter can open and close the entrance to the capillary. Sphincter is unable to contract when blood flows into capillary bed at high pressure, then the fluid from capillaries pass into interstitial space and edema may result.

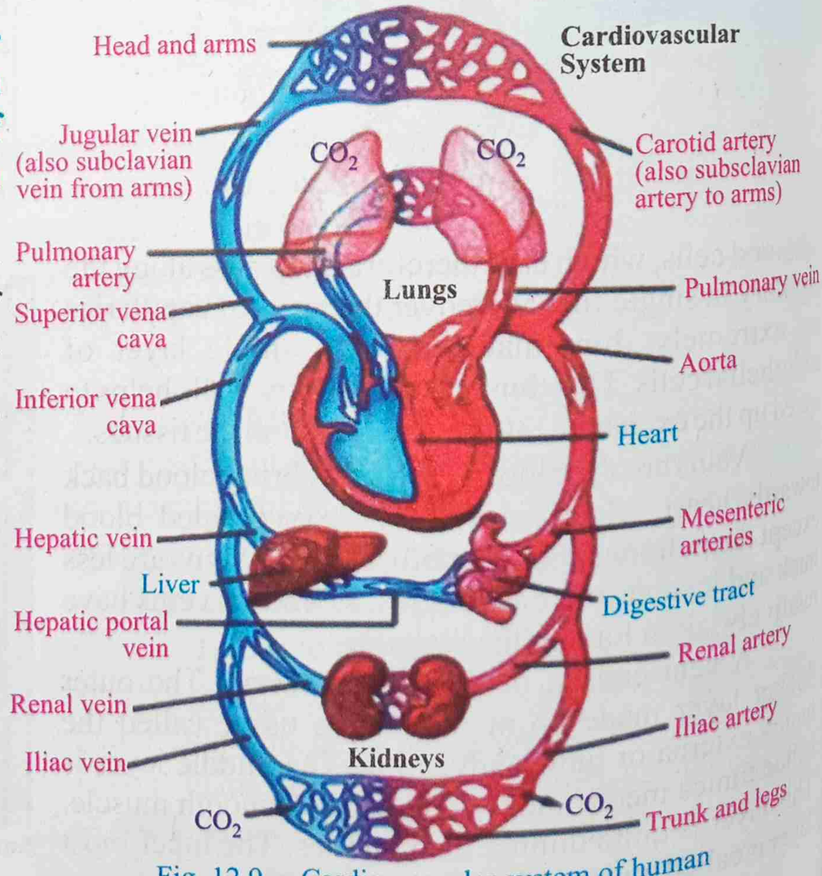


Fig. 12.9 Cardio-vascular system of human

12.3.3 Vascular Pathway

The blood vascular system may be divided into two parts i.e. pulmonary circulation and systemic circulation.

Pulmonary circulation:

The pulmonary circulation is also called pulmonary circuit. This portion of blood circulatory system carries deoxygenated blood away from the right ventricle of heart to lungs and returns oxygenated blood to left atrium and then into the left ventricle of the heart. The deoxygenated blood leaves the heart through pulmonary arteries while oxygenated blood enters into left atrium through pulmonary veins.

Systemic circulation:

The systemic circulation is the portion of the blood vascular system which transports, oxygenated blood away from the heart through the aorta from the left ventricle. This oxygenated blood is transported to all parts of body including heart muscles but excluding lungs. The left atrium is receiving and left ventricle is pumping chambers for systemic circulation. The right atrium is the receiving chamber of systemic circulation. It receives deoxygenated blood through inferior and superior venae cavae.

> **Tit bits**
>
> *Portal hypertension is a condition in which the blood pressure of the portals system is too high which may cause cirrhosis of liver.*

Coronary circulation:

The circulation of blood into the blood vessels of heart muscles i.e., myocardium is known as coronary circulation. Two coronary arteries originate from the left side of the heart at the beginning of aorta. There are two main coronary arteries i.e. left coronary which supplies oxygenated blood to left side of heart and right coronary artery which supplies oxygenated blood to the right side of heart. The deoxygenated blood is taken back to right atrium by cardiac veins.

Hepatic portal system:

The portal system is formed when a capillary bed pools into another capillary bed through veins without going through the heart. The some examples of the portal system are hepatic portal system and renal portal system in poikilotherms. The hepatic portal system is a system of veins related to digestive tract and its tributaries. It is also called the portal venous system. Hepatic portal system is responsible for directing blood from digestive tract to liver. So the substance absorbed in the small intestine travel first to the liver where these are metabolised and processed before sending towards the heart.

> **Tit bits**
>
> *When the heart`s natural pacemaker is defective then the rhythm of heart disturb. This may cause many problems and prove fatal. Therefore artificial pace maker is needed for regulating the heart`s rhythm.*

> **Tit bits**
>
> *The hepatic portal system is present in all vertebrates while renal portal system present only in poikilotherms vertebrates.*

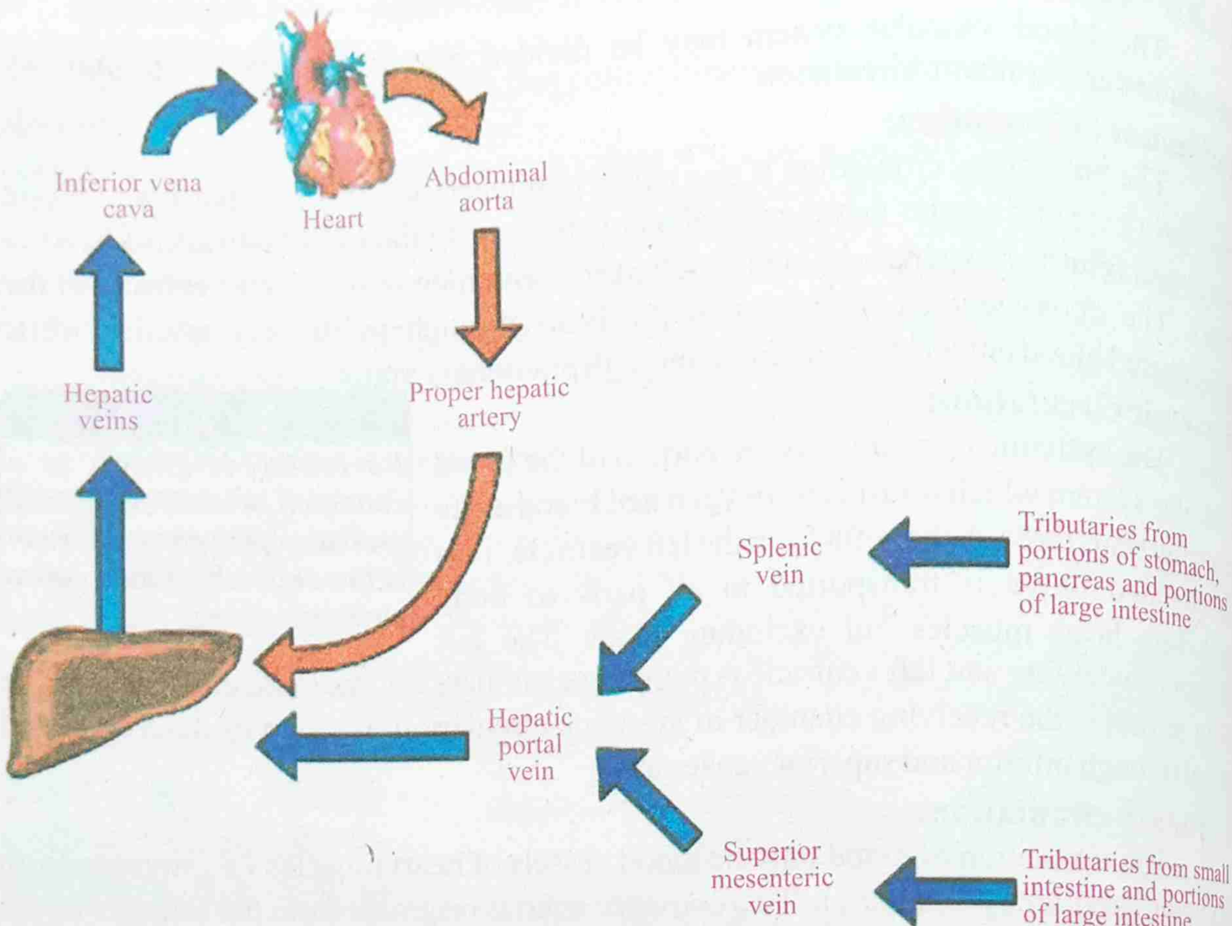


Fig. 12.10 Hepatic Portal Circulation

Renal circulation:

Renal circulation implies the circulation of blood to the kidney via renal artery for filtration and the collection of filtered blood towards heart. Renal arteries normally arise from the side of the abdominal aorta and supply blood to kidneys. The renal arteries carry large portion of total blood flow to the kidneys. Up to one third of total cardiac output can pass through the renal arteries to be filtered by kidneys.

Rate of blood flow in blood vessels:

Blood is circulated around the body through blood vessels by the pumping action of the heart. The rate of blood flow varies greatly in different blood vessels and tissues. It is high in larger vessels and decreases with the division of blood vessels and lowest rate is observed in capillaries.

> **Tit bits**
>
> *Liver has the most abundant blood supply with approximate blood flow of 1350ml/min. kidneys and brains are second and third most supplied organs with 1100 and 700 ml/min respectively.*

12.4 Blood pressure

The term blood pressure refers to the force exerted by the blood on the walls of blood vessels as it passes through them. Blood pressure is most commonly measured via a **sphygmomanometer** in which the height of a column of mercury reflects the circulatory pressure. There are two different pressures which are commonly measured, systolic pressure and diastolic pressure. The **systolic pressure** is the maximum pressure produced in the left ventricle during systole. The **diastolic pressure** is the pressure in the aorta at the end of diastole.

> **Tit bits**
>
> *Baro reflex is one of the blood homeostatic mechanisms that helps to maintain blood pressure.*

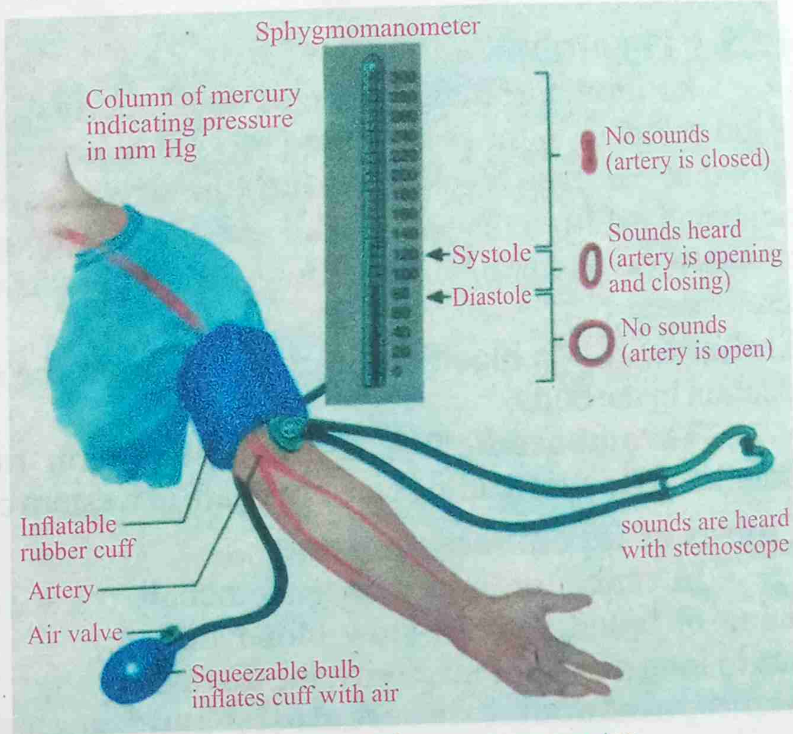


Fig. 12.11 Sphygmomanometer

Baroreceptors:

The blood vessels of vertebrates posses baroreceptors which sense the blood pressure. Then relay the information to the brain so that proper blood pressure can be maintained. These receptors are also called as **pressure receptors**.

On the bases of blood vessel baroreceptors can be divided into two types. **High pressure arterial baroreceptor** and **low pressure baroreceptors** also known as cardiopulmonary or volume receptors.

High Pressure Arterial Baroreceptors:

These receptors are located in the walls of aorta and carotid arteries. These receptors sense the blood pressure and convey the information to the nervous system as per need of the body.

Low Pressure Baroreceptors: (volume receptors)

These receptors are located in atria of the heart, carotid arteries and pulmonary vessels. When low pressure is detected the signal is transmitted by these receptors to the hypothalamus in the brain. The hypothamus increases the production of vasopressin which cause water retention in blood. This increases the blood volume as a result blood pressure also increases.

Comparison of the rate of blood flow through arteries arterioles, capillaries, venules and veins:

The rate of blood flow varies in different blood vessels. In arteries blood flow is

highest as it is pushed out of heart. In adult human, the rate of blood flow in blood vessels at rest (cardiac out put) is about 5 liters/min.

In capillaries blood pressure is lowest while in veins blood pressure is still low as compared to arteries.

12.5 Cardiovascular Disorders

The disease of heart and blood vessels are known as cardiovascular disorders (CVD). Some examples of CVD are.

Do you know?

Thrombus is formed, from the platelets, fibrinogen; entrapped RBC and WBC mostly.

12.5.1 Thrombus

A thrombus is a blood clot that is formed in the blood vessel or in the heart during life and remain there. A thrombus can even block blood flow through a vessel or it can break off from the vessel wall and carried through the circulatory system. The formation of thrombus is called thrombosis.

Tit bits

Up to 90% of cardio vascular diseases may be prevented if established risk factors are avoided.

Embolus: It is a blood clot that travels from the site where it is formed, to another location in the body.

Thromboembolism is a collective term for the formation of thrombus and embolus. Which is leading cause of death in western civilization.

Causes of thromboembolism:

Infection or injury in endothelial lining of blood vessels, slow blood flow due to long period of inactivity, the disease like pneumonia, tuberculosis and emphysema.

Effect of thrombosis: Hypertension due to blockage of blood vessels either partly or completely. It blocks supply of oxygen which result in damage, destruction or even death of tissue (necrosis) in that area.

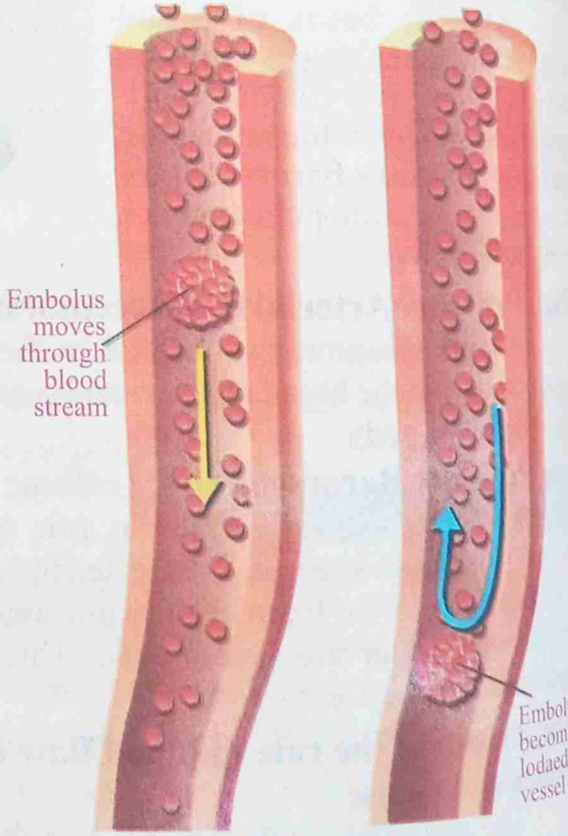


Fig. 12.12 Embolism

12.5.2 Atherosclerosis: (Gk. Athere; Porridge; skeleroe: Hardening)

It is storage of fat deposits on the inside wall of artery. Atherosclerosis is the co-existing antheroma and arteriosclerosis.

The deposition of hard yellow fatty masses called **plaques**, containing large quantities of cholesterol in the inner most

layer (intima) of the arteries is called **atheroma.**

Arteriosclerosis: It is degenerative arterial change associated with advancing growing age primarily a thickening of middle layer of arteries. It causes the arterial lining much rougher than normal. This roughening tends to promote thrombus formation and lead to embolism. It also causes narrowing of blood vessels due to deposition of plaque which obstructs the flow of blood. Ca ions also deposit in the plaque, which loses (weakens) their elasticity and easily gets ruptured.

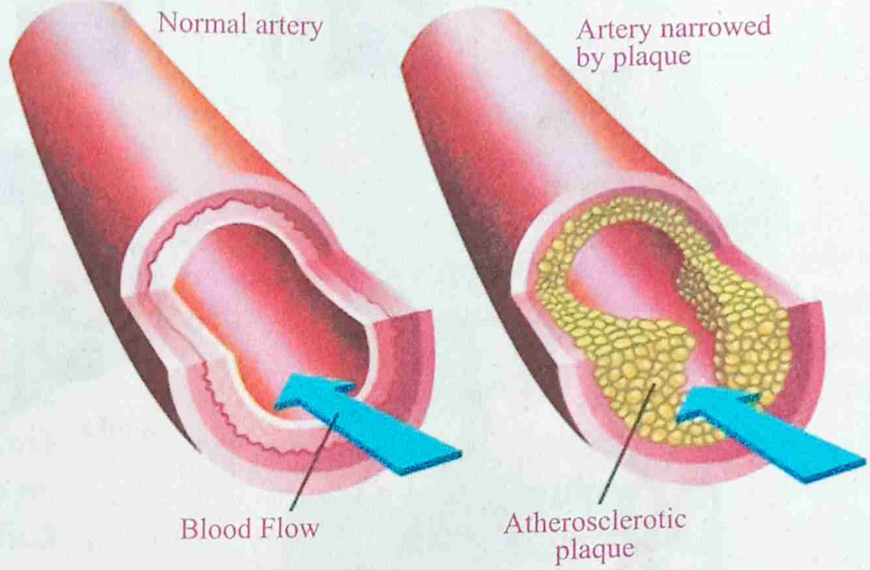


Fig. 12.13 Atherosclerosis

Causes of atherosclerosis:
Hypertension, smoking, hyper lipidemia, diabetes mellitus, lack of exercise and obesity.

Prevention: Do exercise regularly, avoid smoking, use of low cholesterol diet.

Angina Pectoris: If a coronary artery become partially blocked, the individual may suffer from angina pectoris (i.e., chest pain along with pain in the left arm). Angina is an alarming signal that heart is not receiving sufficient supply of oxygen and in future heart attack may occur. **Nitroglycerine** mostly helps to relieve the pain in angina pectoris, because this drug dilates the blocked blood vessels.

12.5.3 Heart Attack

Heart attack is the sudden death of a part of the heart muscle without warning due to sudden reduction of blood supply.

Heart attack mostly occurs when atheorsclerosis reach a critical level and damage large portion of heart or some time a blood clot may causes blockage of blood supply in coronary vessels.

The above factors cause death of a part of heart and the whole process is called myocardial infarction (Myo; muscle, cardium; heart, infarction; death due to lack of

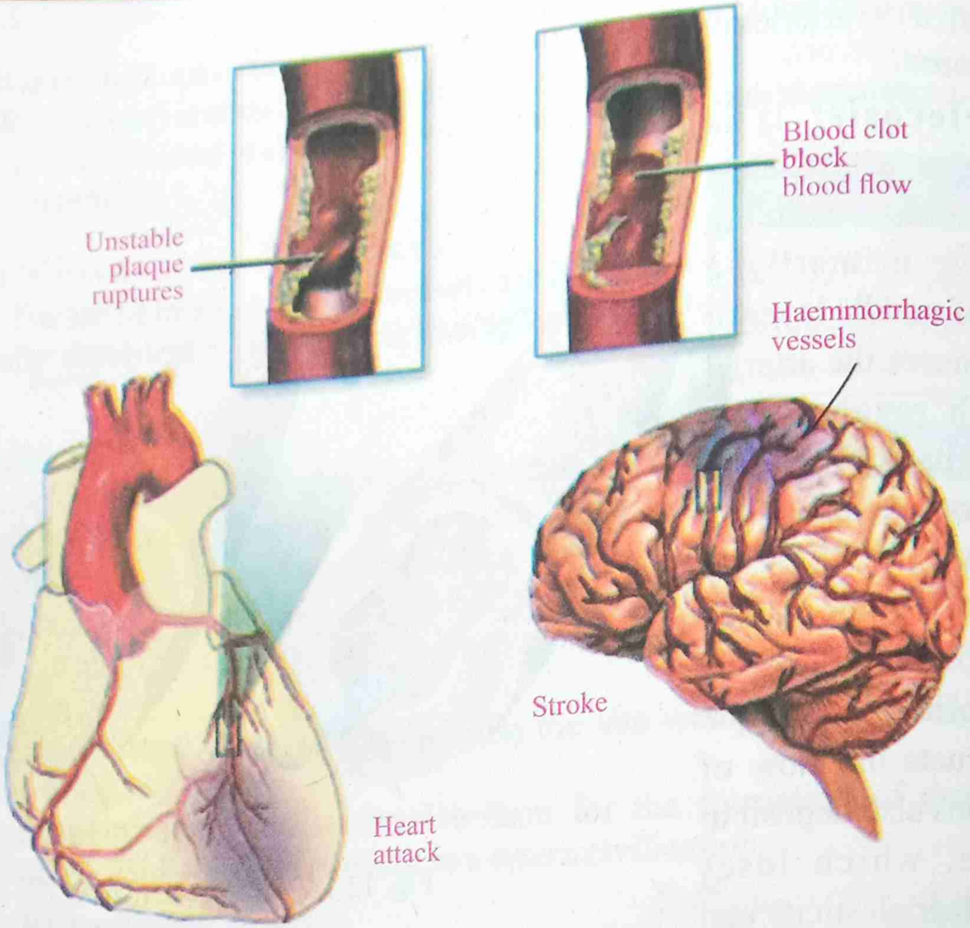


Fig. 12.14 Heart Attack and Stroke

oxygen). Myocardial infarction occurs mostly in individual over 45 year of age. Each year about more than one million people die due to heart attack. Males are more likely to suffer heart attack than females and also smokers than non-smokers.

Heart Failure: It is a clinical syndrome resulting from deficient cardiac volume, relative to body need, with inability of the cardiac output to keep pace with the venous return i.e, heart is unable to pump all the blood coming to it.

Congestive heart problem: It is abnormal function of cardiac valves. **Valvular stenosis** (Narrowing of heart valves due to scarring of its cusps) reduces the diameter of the valve orifice. Severe destruction of valve apparatus may cause valve ring dilation, the **chordiae tendinae** become thicken and shorten, this results in regurgitation of blood through the valve when it is incompletely closed.

12.5.4 Patent Ductus Arteriosus: (PDA)

It is disease of child hood(infant). In fetus, ductus arteriosus is a blood vessel which links the pulmonary artery with aorta. Just after birth when the baby takes its first breath, the lungs become functional and the placenta is cut off, the ductus arteriosus become closed.

Sometimes it fails to do so. This causes **blue babies** due to mixing of oxygenated

and deoxygenated blood.

The symptoms include high heart beat, shortness of breath, respiratory problems etc. The causes are usually unknown but may be due to preterm birth, chromosomal abnormalities and this disease is treated by surgical procedure. Untreated PDA may lead to heart failure and death.

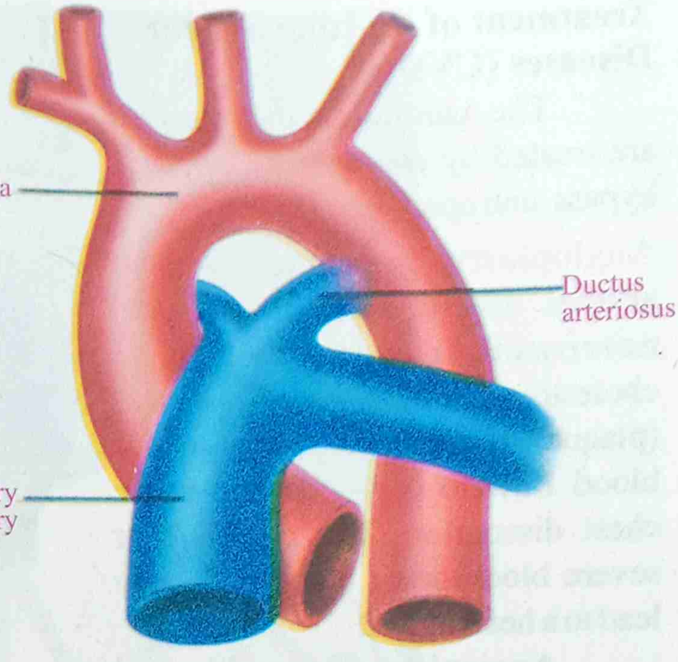


Fig. 12.15 PDA

Do you know?

PDA is usually diagnosed using non-invasive technique like echocardiography.

Angiography: It is a test in which dyes that can be seen by x-rays are injected into blood vessels (either arteries or veins) and are examined by x-rays. The resulting pictures are called angiograms. The angiograms are used to diagnose the narrowing or the blockages in vessels anywhere in the body.

The angiography can also be used to find places where arteries and veins are bulging or ballooning. These spots are called aneurysms and if this is not treated can cause death when these vessels rupture.

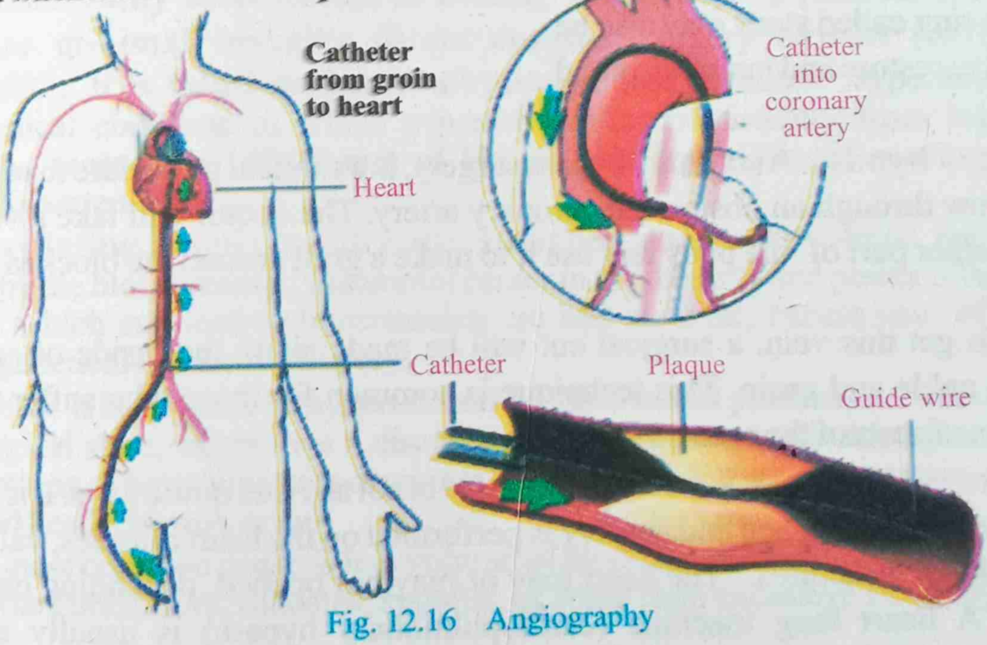


Fig. 12.16 Angiography

Treatment of Cardiovascular Diseases (CVD):

The cardiovascular diseases are treated by angioplasty, coronary bypass and open heart surgery.

Angioplasty: Sometimes our heart arteries may become blocked and narrowed from a buildup of cholesterol, cells or other substances (plaque). If it happens, it can reduce blood flow to our heart and cause chest discomfort. The complete or severe blockage of blood flow may lead to a heart attack.

Angioplasty opens blocked arteries and restores normal blood flow to our heart muscle. It is not major surgery. It is done by threading a **catheter** (thin tube) through a small puncture in a leg or arm artery to the heart. The blocked artery is opened by inflating a tiny balloon in it which forces the blood vessel to widen. A metallic ring called **stent** may also be inserted to restore and maintain blood flow.

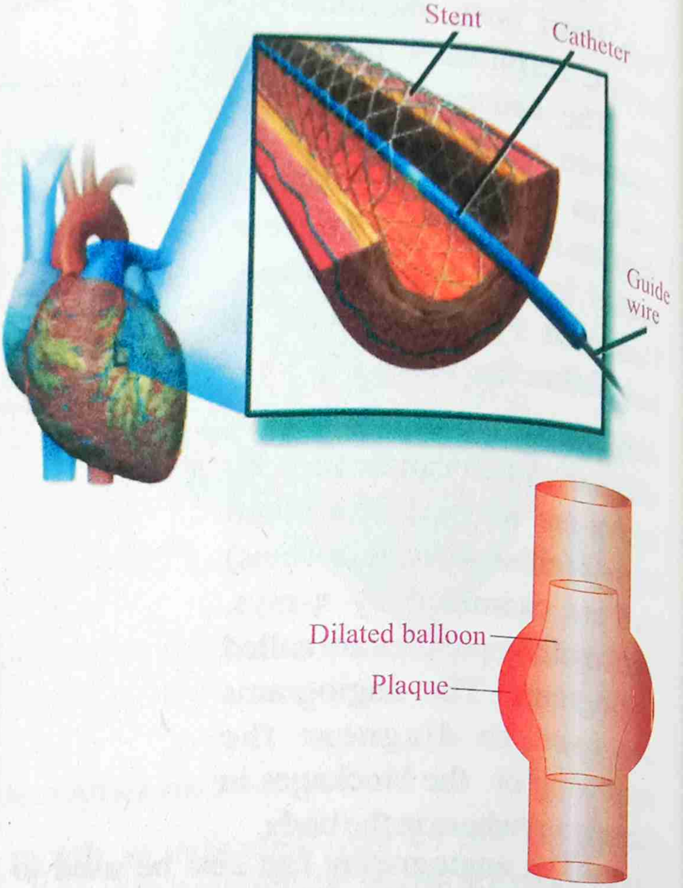


Fig 12.17 Stent in Coronary Artery

Coronary bypass: A coronary bypass surgery, is a surgical procedure to restore normal blood flow through an obstructed coronary artery. The doctor will take a vein or artery from another part of the body and use it to make a graft around the blocked area in your artery.

To get this vein, a surgical cut will be made along the inside of patients leg, between ankle and groin. This technique is common for those who suffer from severe occlusion of parts of the coronary arteries.

Open heart surgery: It is an old therapy and is not advised now a days. It is a surgery, in which the chest is opened and surgery is performed on the heart muscles, valves, arteries or other heart structures. The heart may or may not opened, depending on the type of surgery. A heart lung machine (cardiopulmonary bypass) is usually used during

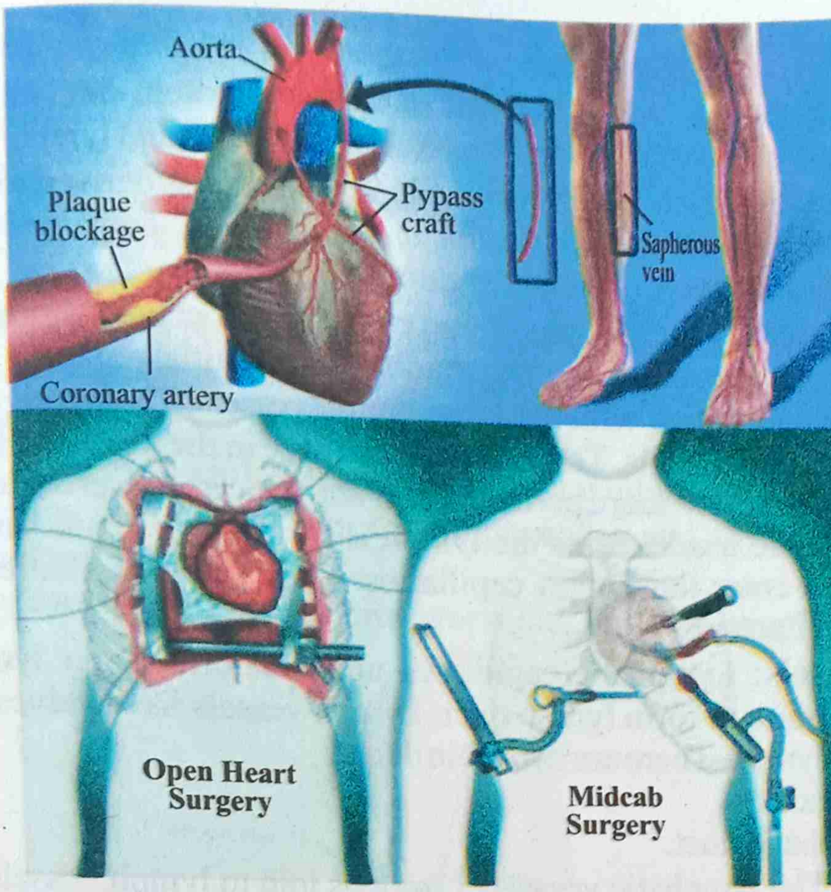


Fig. 12.18 Heart Surgery

conventional coronary artery bypass graft(CABG) surgery. After completion of surgery and the heart beat is started and provides blood and oxygen to the body the chest is again closed. There are some new surgical procedures being performed that are done in which the heart continuously beats termed as **beating heart surgery** (smaller incisions in sternum) or minimal invasive direct coronary artery bypass (MIDCAB).

Hypertension: It is called mother of all physiological diseases. Hypertension is a chronic medical condition in which a person suffers persistently from high blood pressure. i.e., more than 140/90 mm of Hg, at least two different reading apart is considered hypertension.

Factors regulating blood pressure are: Heart beat rate, stroke volume, resistance to blood flow by the blood vessels, vasomotor center in the medulla and power of heart beat. The factors which can lead to hypertension are less exercise, excess use of alcohol, ageing and genetical i.e., family history.

Hypotension: It is opposite to hypertension i.e, (**low blood pressure**). It is considered as physiological state, rather than a disease, not always but mostly due to shocks. The initial symptoms of hypotension is dizziness, fainting and seizures, chest pain, shortness of breath and headache may occur.

The most common cause is less volume of blood flow through body. It also occur in disease like Parkinson's, diabetes, syphilis, or some time excessive sweating and less fluid intake.

12.6 Lymphatic System in Human

The lymphatic system is neither closed circulatory system nor does it have pump, comprises of lymph capillaries, lymph vessels, lymph nodes and lymph.

Lymph: It is colorless fluid with in lymphatic vessels, that is derived form blood vessels (Blood plasma) and resembles to plasma in composition, contains WBC (no RBC), contains large protein, which ultimately returns to the blood.

Lymph Capillaries: These are small blind ended tubes occur in almost all tissues of all organs. They have no opening at the end, residing in interstitial regions.

They unite and merge with the large lymph vessels. Their wall consist of only a single layer of endothelial cells. The intercellular space in their wall are longer than those of the capillaries. Therefore more permeable for substances in intercellular fluid. As they are blind ended in the tissues, thus the lymph is forced by the pressure created in the interstitial fluid to enter the lymph capillaries. The lymph capillaries in the villi of intestine are called Lacteals.

Lymphatic Vessels: Lymphatic capillaries unite to form larger lymphatic vessels, which ultimately unite to form lymph duct. Lymph vessels have valves, which prevent backward flow of lymph. There are two main ducts.

i) Thoracic duct

ii) Right lymphatic duct.

Thoracic duct: The lymphatic vessels of the legs join to lymph vessels of alimentary canal and then to form the thoracic duct which empties lymph into the left subclavian.

Right Lymphatic duct: It drains lymph from the right anterior parts of the body and finally enters into the right branchiocephalic vein.

Lymph nodes: These are aggregations of lymphoid tissues having lympocytes which are small, rounded, oval or bean shaped structures, consist of lymphocytes, connective tissues and lymph vessel.

Location: In neck region, abdomen, armpit, groin, elbow and knee joint. etc.

Functions of Lymph nodes

i) Produce lymphocytes and antibodies for the defense of the body

ii) They also filter lymph (make germ free)

iii) Destroy worn out RBCs.

Lymph Masses

There are many lymphoid masses present in the wall of digestive tract in the mucosa and submusoca. The larger masses are spleen, thymus, tonsils and adenoids are all lymphoid aggregation which functions to produce lymphocytes.

Flow of Lymph in lymph vessels

The circulation of lymph is brought about by:

- Contractility of lymph vessels.

Activity of skeletal muscles, during general body movement and massage or physiotherapy.

- Movement of visceral organs.

Breathing movement

- The valve present in the wall of lymph vessels, which permit the lymph flow is only one direction i.e., towards hearts.
- The lymph from lymph duct poured into the subclavian veins.

Function of lymphatic system:

Control tissue fluid: About 3 liters fluid leaves the blood capillaries in an adult person per day. This fluid and its proteins and many other substances from the cell are returned by lymph back into the blood, and thus tissues do not face the problem of excess fluid in their intercellular space.

Transport of fatty acid and glycerol: by lacteal at villus level of ileum.

Production of lymphocytes by lymph nodes and thymus which destroy the bacteria, thus helps in defense.

Destroy and eliminate old and worn out RBC In lymph nodes especially in spleen.

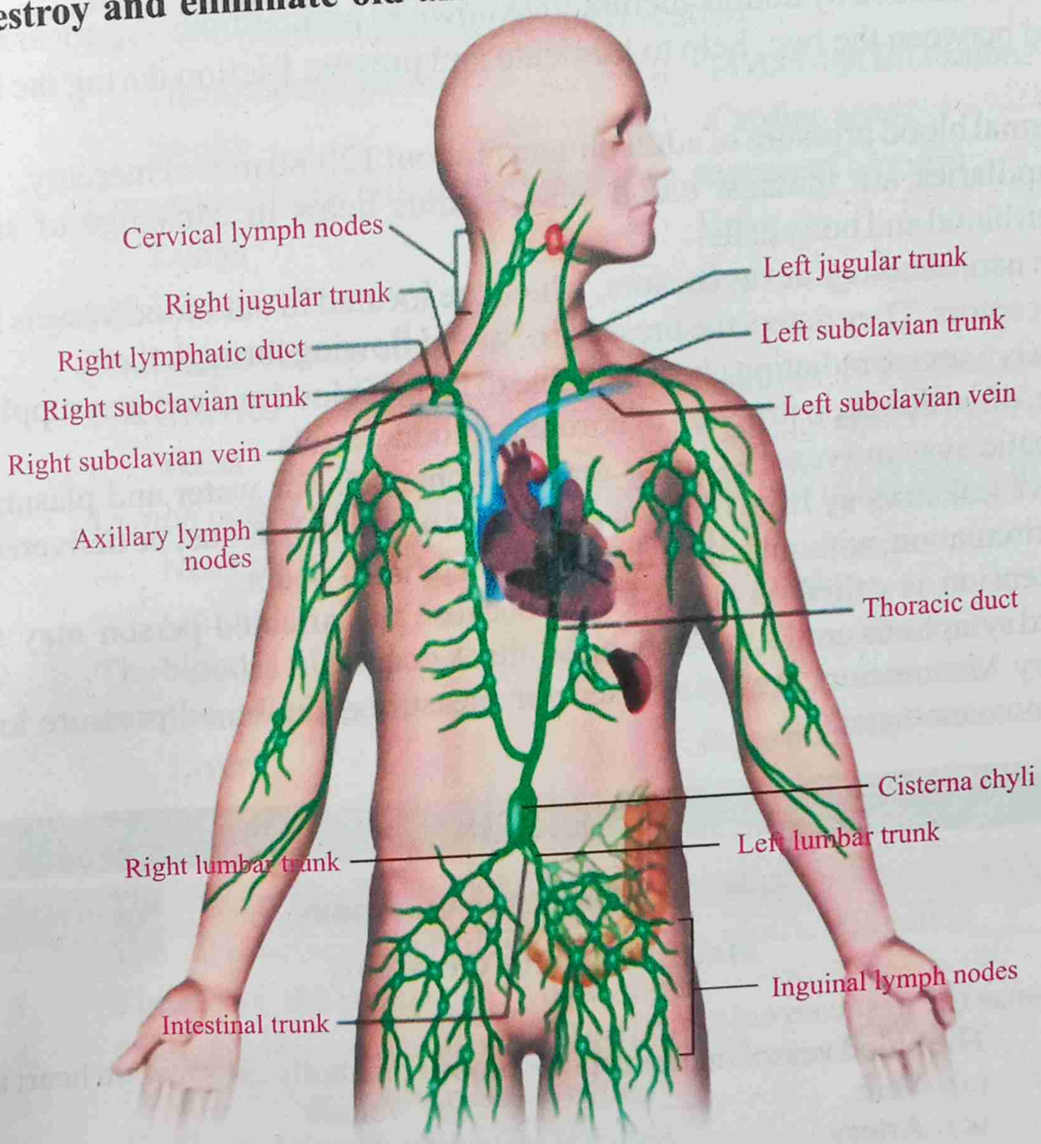


Fig. 12.19 Lymphatic system

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A. Choose the best correct answer.

1. The blood vessel that transports blood from body cells toward heart is
   (a) Vein (b) Venule
   (c) Artery (d) Arteriole

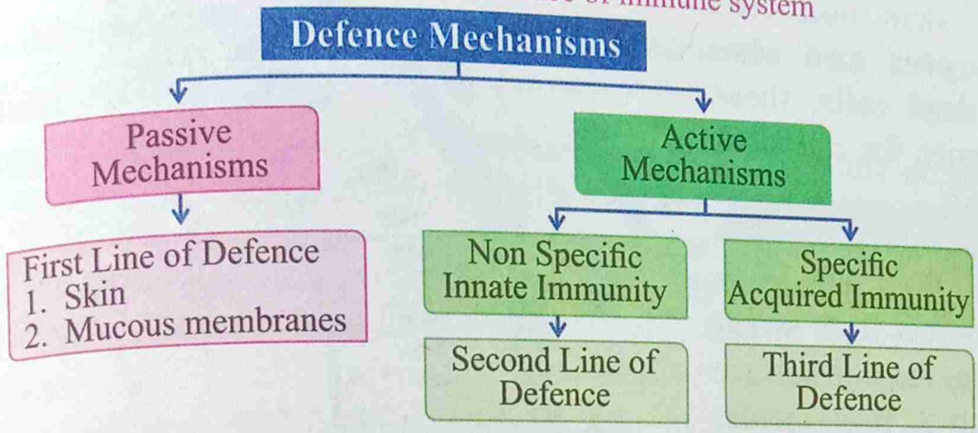
2. Which layer in arteries can withstand higher blood pressure during ventricular systole?
   (a) Outer layer (b) Middle layer
   (c) Inner layer (d) All these
3. The arteries divide into smaller vessels called
   (a) Arterioles (b) Capillaries
   (c) Venules (d) Veins
4. Artherosclerosis is mainly because of deposition' of which of the following.
   (a) High level of cholesterol (b) Low level of cholesterol
   (c) High level of phospholipids (d) Low level of phospholipids
5. Blockage of blood vessel in the heart by an embolus causes necrosis or damage to portion of heart muscles is called
   (a) Thromboembolism (b) Myocrdial infarction
   (c) Stroke (d) Cardiac arrest
6. Congestive heart failure is because of retention of blood in
   (a) Lungs (b) Heart
   (c) Liver (d) Both lungs and heart
7. The lymph vessels empty in
   (a) Arteries (b) Arterioles
   (c) Veins (d) Capillaries
8. Lymph nodes are not present in which of the following region in humans.
   (a) Neck region (b) Axilla
   (c) Groins (d) Stomach
9. The blood is filtered at
   (a) Lymph nodes (b) Spleen
   (c) Liver (d) Bone marrow

B. Fill the blanks

Introduction

We are living in the sea of micro-organisms. Most of these organisms are our friends. However, some of them are our enemies. These enemies invade our body continuously. To counter attack these invaders, our body has developed a system called **immune system.** The immune system consists of many biological structures and processes within an organism that protects against diseases. This ability of an organism to combat diseases and pathogen is called **immunity.** The study of immunity is called **immunology.** In this chapter we will discuss three lines of defence of immune system.

Table 13.1 Lines of defence of immune system



13.1 First Line of Defence (Layered Defence)

The first line of defence is non specific and part of innate immunity (present naturally at the time of birth). It is the best defence as it keeps pathogens out of the body. It consists of following parts.

> **Tit bits**
>
> *The word skin is derived from Latin word "cutis" In mammals it is the largest organ of the body. It has many functions like protection, sensation, heat regulation, control of evaporation, excretion etc.*

13.1.1 Skin

Skin is the largest organ of the vertebrate body accounting for 15% of an adult human's total weight. The skin not only defends the body by providing nearly impermeable barrier but also reinforces this defence through chemical weapons on the surface.

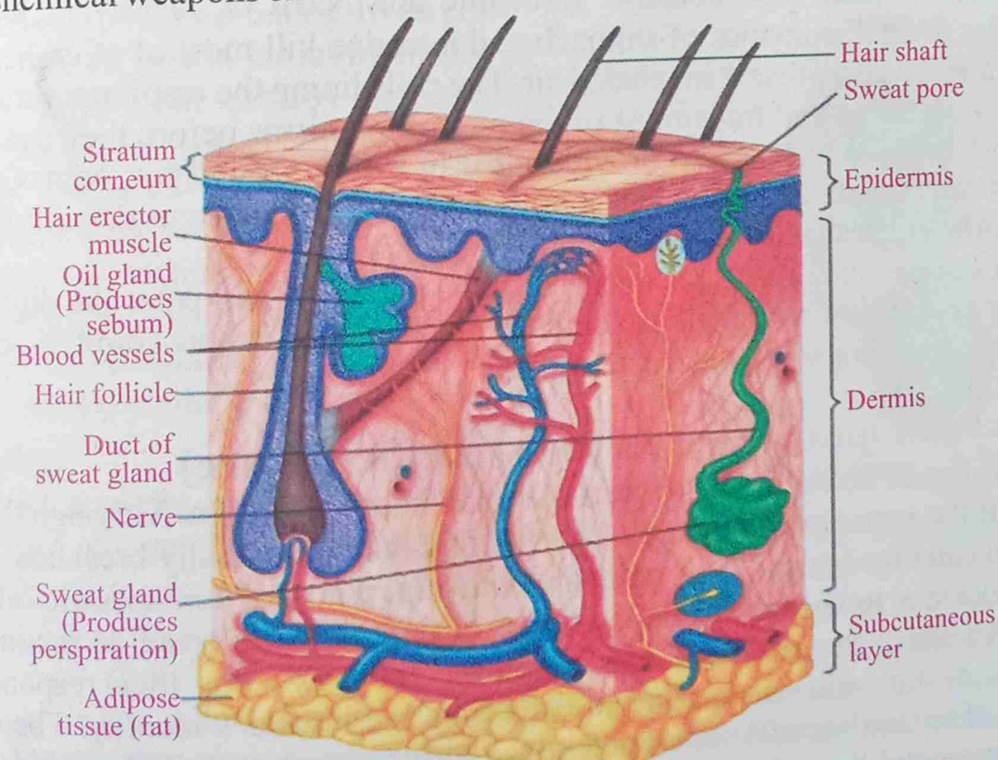


Fig. 13.1 Skin as first line of defence

The skin contains **keratinocytes** and also possesses dead cells, these become barrier for microbes to get entrance.

The dermis of skin produces oil from **sebaceous** glands and sweat from **sweat glands,** gives the skin surface a pH of 3 to 5. It is acidic enough to inhibit the growth of many micro-organisms. Sweat also contains the **lysozymes,** which digest bacterial cell wall. These also contain natural antibiotic (such as lactic acid).

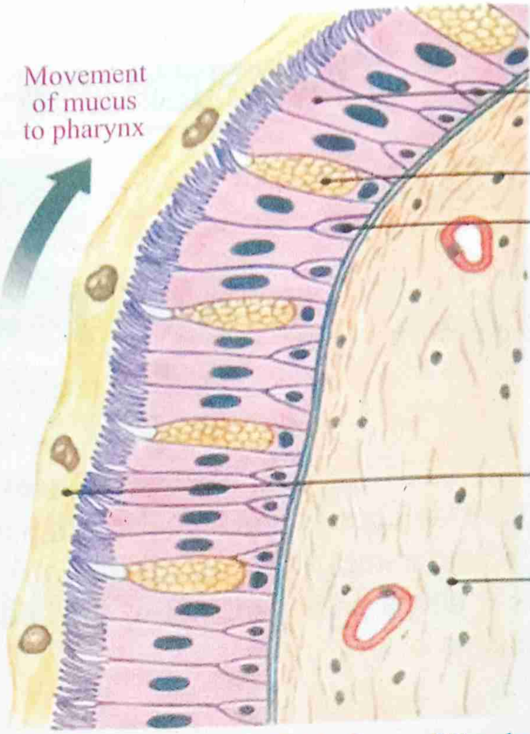


Fig. 13.2 Respiratory Epithelium of Trachea

13.1.2 Digestive and Respiratory tract

Both the digestive and respiratory tract open to the out side and their inner surfaces must also be protected by foreign invaders. Microbes are present in food but many are killed by saliva which also contains lysozyme and $NaHCO_3$. The very low pH of stomach due to HCl, enzymes of stomach and intestine kill most of microbes of food. Micro-organisms also present in inhaled air. The cells lining the respiratory tract secrete layer of sticky mucus that traps most of the micro-organisms before they can reach the warm moist lungs, which would provide ideal breeding ground for them. Other cells lining in these passages have **cilia** that continuously sweep the mucus towards the glottis. There it can be either swallowed or spit out.

Occasionally an infectious agent, called a pathogen will enter the digestive and respiratory system and body will use defence mechanisms such as vomiting, diarrhoea, coughing and sneezing to expel the pathogens.

13.2 Second Line of Defence: (non specific defence)

This line of defence is also a part of innate immune system. Although the surface defences of the vertebrate body are very effective but occasionally breached allowing invaders to enter the body. At this point the body uses a host of non-specific cellular and chemical devices to defend itself. This type of defence is referred as second line of defence. All these devices have one common property i.e., they respond to any microbial infection without pausing to determine the invader's identity. The cells and chemicals of second line of defence, defend the body to attack and kill the invaders.

The second line of defence consists of three types of mechanisms i.e., natural

killer cells, inflammatory responses and temperature responses.

13.2.1 Killing cells of blood

Perhaps the most important of vertebrate body's non-specific defence are the white blood cells called leucocytes. These cells circulate through the body and attack invading microbes within tissue. There are three basic kinds of these cells and each kill invading micro-organism differently.

> **Do you know?**
>
> *How neutrophil is different from lymphocytes, second line of defence and third line of defence.*

Macrophages:

The macrophages (Big eaters) are large irregularly shaped cells that kill microbes by ingesting them through phagocytosis (like *Amoeba*).

They are found in organs such as lungs, liver, spleen, kidney and lymph nodes rather than remaining in the blood.

They leave the bone marrow and travel into the blood as monocytes, where they develop into macrophages. Once they leave the blood and settle in the organs, they remove any foreign matter found there.

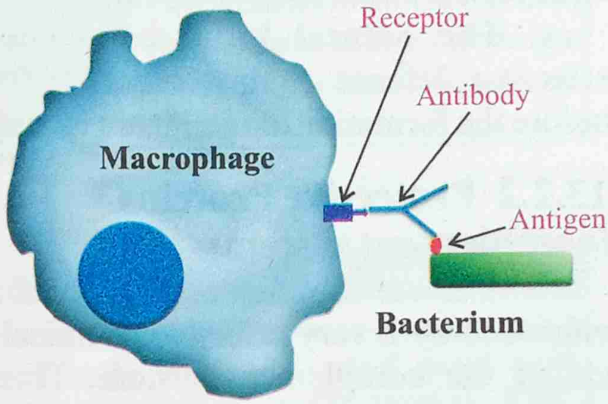


Fig. 13.3 Macrophage

The macrophages are long-lived cells. They play a crucial role in initiating immune response. They do not destroy pathogens completely but cut them up to display antigens that can be recognized by lymphocytes. Macrophages secrete some types of proteins which trigger maturation of monocytes. A protein interleukin-I stimulate the hypothalamus to raise body temperature, and other protein stimulate the specific response.

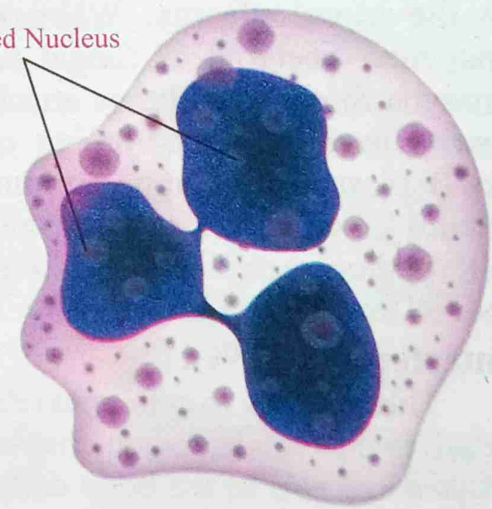


Fig. 13.4 Neutrophils

Neutrophils:

The neutrophils are types of white blood cells that, like macrophages destroy the pathogens by phagocytosis. In addition neutrophils release lysozyme, chemicals that kill other bacteria in the neighbourhood. Neutrophils have short life span, after killing and digesting some pathogens they die. Dead neutrophils are collected at the site of infection to form pus. Due to psuedopodial movement, their body squeeze and can enter all those parts of tissues where other WBC can not enter. These are most abundant types of WBCs in most mammals, about 40 to 70%.

Natural killer cells:

These cells do not attach invading microbes directly instead they kill cells of the body that have been infected. They do not phagocytose microbes but rather by creating a hole in the plasma membrane of target cell. Proteins called **perforins** are released from the membrane of the natural killer cells and inserted into membrane of target cell which then swell and bursts,by a protease (enzyme).

The natural killer cells cause very effective defence against cancer cells usually before the formation of malignant tumor.

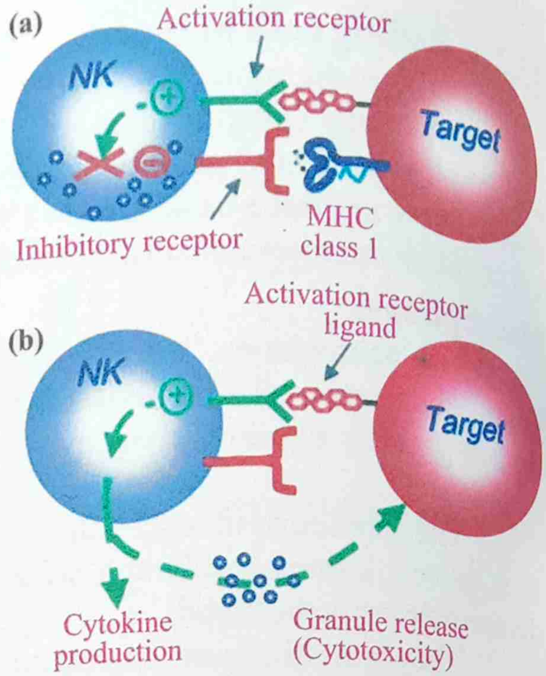


Fig. 13.5 Natural Killer Cell (NK)

> **Activity**
>
> *Justify why the physicians prescribe antipyretic drugs, when fever is a nonspecific defence against microbial infection.*

> **Tit bits**
>
> *Aspirin reduce the degree of fever because aspirin impedes the formation of prostagladin from arachidonic acid. Drugs like aspirin that reduce fever are called antipyretic.*

> **Activity**
>
> *How antihistamine therapy is helpful to the patients of runny nose and skin rashes?*

13.2.2 Protective Proteins (complement system)

The cellular defence of vertebrates are enhanced by a very effective chemical defence called the complement system. This system consists of approximately 20 to 30 different proteins formed in the liver, that circulate freely in the blood plasma. When these proteins encounter bacterial or fungal cells then these proteins form a membrane attack complex that inserts itself into the foreign cells (pathogen cells) plasma membrane forming a pore like natural killer cells. The water enters the foreign cell (pathogen cells) through this pore causing, the cell to swell and burst.

Interferons (IFNs):

These belong to cytokines (Protein in lymph cells). Interferons is another class of proteins that plays a key role in the body defence. There are three major categories of interferons. These are grouped into two types. Type I, alpha and beta while type II is gamma. These cells of the body synthesize alpha and beta interferons. These polypeptides act as messengers, that protect normal cells in the vicinity of infected cells from becoming infected. Though viruses are still able to penetrate the neighbouring cells. The **alpha and beta interferons** prevent viral replication and protein assembly in these cells. (Thus named interferons means interfere with viral replication inside body cell).

Gamma interferon is produced only by particular lymphocytes and natural killer cells. Gamma interferons defend against infection and cancer. These also activate other immune cells such as macrophages and natural killer cells.

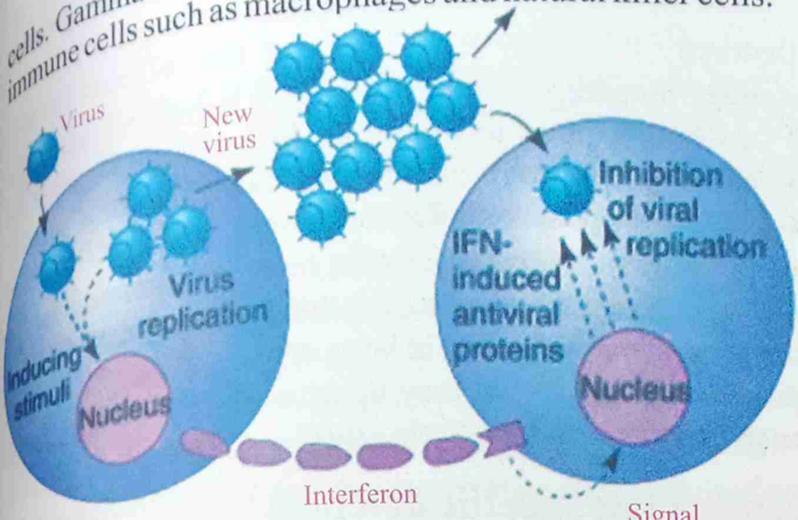


Fig. 13.6 Interferons

Tit bits

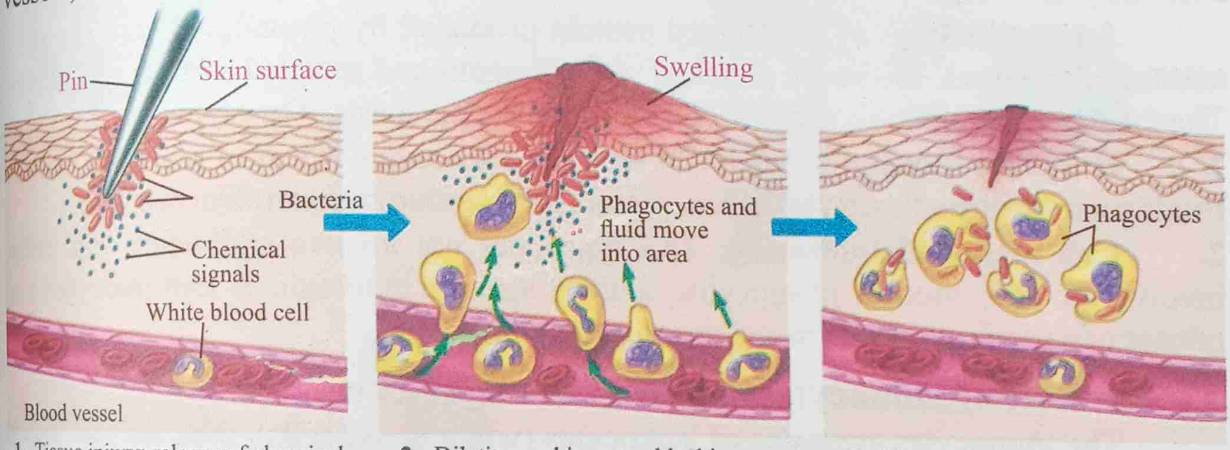
Invading bacteria and viruses are recognized as foreign because they contain molecules, which are different from any of our own molecule. These foreign molecules are known as antigens.

Inflammatory Responses:(means setting on fire)

The inflammatory response is a localized, nonspecific against infection. Infected or injured cells release chemical alarm signals, most notably **histamine and prostaglandins** (Produced from all nucleated cells). These chemicals promote the dilation of local blood vessels, which

Tit bits

Histamine secreted from basophils and mast cells which are a class of WBC. These cells are filled basophil granules found in number of tissues.



1- Tissue injury; release of chemical signals such as histamine

2- Dilation and increased leakiness of local blood vessels; migration of phagocytes to the area

3- Phagocytes (macrophages and neutrophils) consume bacteria and cell debris; tissue heals

Fig. 13.7 Inflammatory Responses

increase the flow of blood at the site of infection or injury and causes the area to become warm, red, swollen and feel pain. They also increase the permeability of capillaries in the area producing **edema.** Phagocytes migrate from the

Activity

Search net to see the difference between two sub classes of monocytes.

blood to the extra cellular fluid where they can attack bacteria. The function of inflammation is to remove necrotic cells and to start rapair process and prevent spreading of infection.

13.2.4 Temperature Responses

Macrophages that encounter invading microbes release a regulatory molecule called interleukin-1 which is carried by blood to the brain. **Interleukin-1** and other **pyrogens** (Greek Pyr=fire) such as bacterial endotoxins cause neurons in the hypothalamus to raise the body temperature several degrees above the normal value of 37°C (98.6°F). The elevated temperature thus results is called fever. Fever contributes to the body's defence by stimulating phagocytosis and causing the liver and spleen to store iron, reducing blood level of iron which bacteria need in large amount to grow. However very high fever is harmful because excessive heat may denature critical enzymes and proteins of body. Therefore, the patient is given antipyretic drugs.

13.3 Third Line of Defence: (The specific defence)

Many of us contract some sort of infection in our child hood, small pox for example, is an illness that many of us experience before we reach our teens. It is a disease of childhood as most of us contract it in childhood stage and never catch it again. Once you have had the disease, you are usually immune to it. The specific immune defence mechanism provides such immunity.

An antigen is a molecule capable of inducing an immune response in the host. These are usually foreign bodies but sometimes these are part of host itself in an autoimmune disease.

An antibody is a "Y" shaped protein produced by plasma cells to destroy or neutralize antigens. These are attached on pathogens and secreted by B. lymphocytes. The third line of defence is specific and most effective consists of two types.

1. **Humoral immunity,** mediated by macromolecules found in the extra cellular fluids such as antibodies, complement proteins and certain antimicrobial peptides.
2. **Cell mediated immunity:** This type does not involve antibodies; but rather involve the activation of phagocytes, antigen specific cytotoxic T- Lymphocytes and release of various cytokines in response to antigens.

13.3.1 Role of Monocytes in Third Line of Defence

The monocytes are types of leukocytes (white blood cells), they are the largest type of leukocytes. As part of vertebrate innate immune system (discussed in second line of defence), monocytes also influence the process of adaptive immunity. There are at least two sub classes of monocytes in human blood.

I) Dendritic cells:- These are antigen presenting cells, mark out foreign bodies to be destroyed by lymphocytes.

ii) Macrophage:- These are large phagocytic cells.

13.3.2 Role of T-Cells in Third Line of Defence: (cell mediated immunity)

T-Cells or T. Lymphocytes are a type of lymphocytes (a type of WBC) that play a central role in cell mediated immunity. T-cell can be distinguished from other lymphocytes such as B-Cells and natural killer cells by the presence of a T-Cell receptor on the cell surface. They are called T-Cells because they mature in the **thymus** from thymocytes, an endocrine gland in chest (some are synthesized in tonsils also).

Activation of T-Cells: When infection occurs the T-cells detect particular antigen of invading micro-organism by engulfing it. The T-Cells display these antigen on their surface with the help of their own protein known as **Major Histocompatibility Complex** (MHC). In this way, macrophages become **antigen presenting cells (APCs)**. At the same time macrophages release **interleukin 1** that stimulates helper T-Cells and attracts them towards displayed antigen. The helper T-Cells have receptor by which they bind with specific antigen present on APC. The receptor on surface of T-Cells are called T-cell receptor (TCR). The T-cell also stimulated by interleukin to secrete another protein called **interleukin 2** which

> **Tit bits**
>
> *The primary response is slow because at this stage there are very few B-cells that are specific to antigen.*

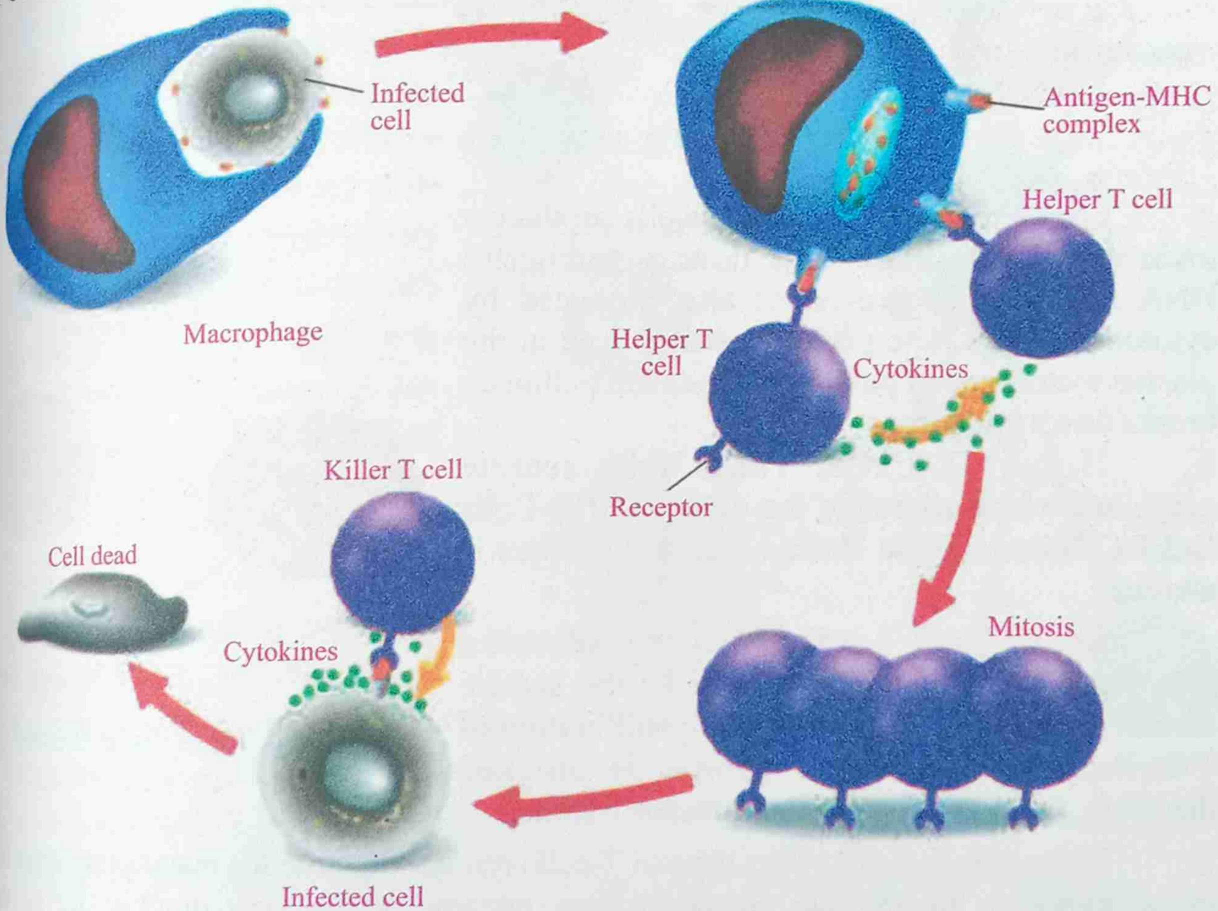


Fig. 13.8 Cell Mediated Immune Response

is not only responsible for division of helper cells but also proliferates certain cytotoxic T- cells and B cells. There are millions of different T-cells, as each type of T-cells respond to a specific type of antigen. This type of immunity is called cell mediated immunity.

Types of T-Cells: The T-lymphocytes are of two types i.e., **CD8** (cluster of differentiation) as they have surface marker CD8, include cytotoxic T-cells and suppressor T-Cells. The other group is helper T-Cells also called **CD4** cells due to presence of surface marker CD4. On activation, the T-Cells divide and produce 4 types of cells, these four types of cell play vital role in cell mediated immune response. The four types of cells produced by T-cells are as follow.

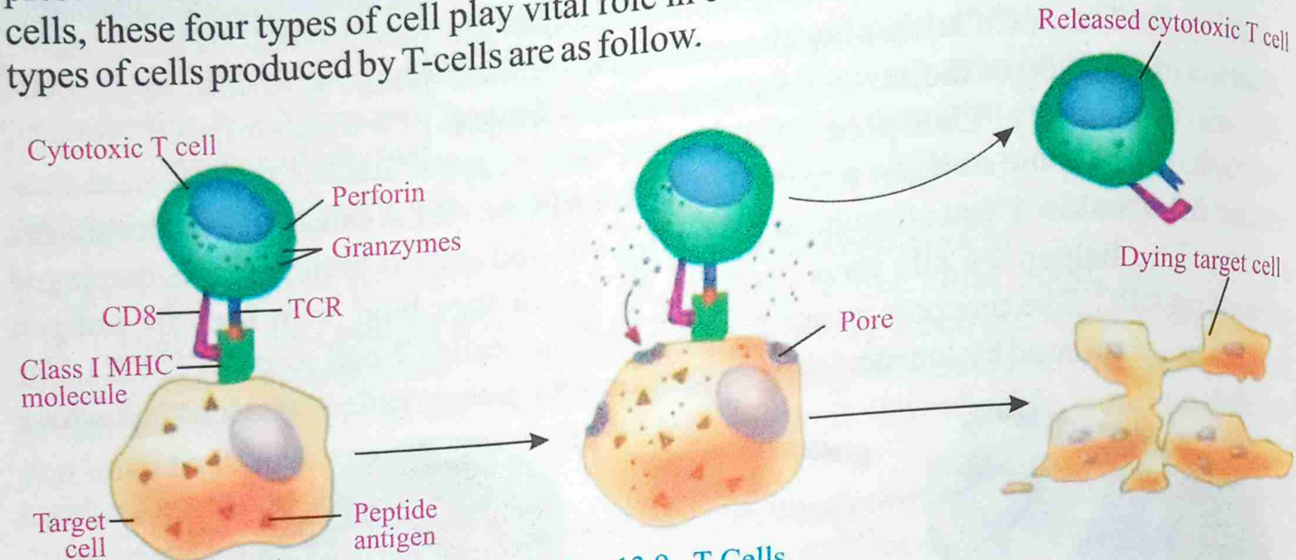


Fig. 13.9 T-Cells

a. Cytotoxic T-Cells: These cells produce a toxin called **cytotoxin.** This destroy pathogen's DNA and perforin protein is also produced by cytotoxic T-cells. The perforin creates hole in the plasma membrane of pathogen as a result pathogen breaks down into pieces.

b. Helper T-Cells: These cells secrete cytokines which stimulate the division of B-Cells and T-Cells to increase defense against pathogenic attacks.

c. Suppressor T-cells: After the successful removal of infection the suppressor T-Cells secrete certain proteins that inhibit further proliferation of T-Cells, Thus immune response is blocked therefore, the cells are called suppressor T-Cells.

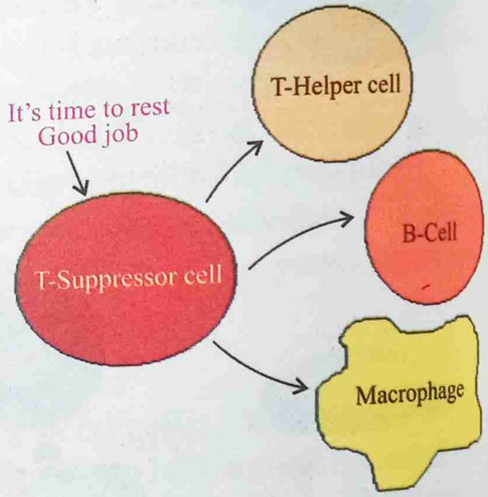


Fig. 13.10 Binary Fission

d. Memory T-Cells: This type of T-cells remain inactive for many years after the initial exposure to antigen. However they become active very quickly during the secondary response to antigen and fight against pathogen.

13.3.3 Role of B-Cells in Third Line of Defence "Humoral immunity" or Antibody Mediated immune response.

The antibodies are small glycoprotein molecules.

B-lymphocytes secrete antibodies, which destroy bacterial pathogens. B-lymphocytes are so called because they develop in the bone marrow and first discovered in the bursa of intestines of birds.

As mentioned earlier in this chapter that antigens are foreign molecules because they are different from any of our own molecules. We have a huge number of B-lymphocytes in our blood each one of them recognizes and responds to one particular antigen. The B-lymphocytes respond by producing antibodies.

Activation of B-Lymphocytes

Most B lymphocytes will spend all their lives without anything happening to them at all because they never meet their particular antigen. But a B-lymplcyte does encounter an antigen which binds to the receptors on its cell surface membrane, it is triggered into action. After encountering its specific antigen, the B-lymphoeyte is stimulated to divide repeatedly by mitosis. Some of these cells differentiate into **plasma cells.** These cells have the ability to produce very large number of antibody molecule in very less time (2000 antibody molecules per second). These antibodies bind with antigens and destroy them.

Other cells produced as a result of mitosis do not secrete antibody, instead they remain as **memory cells**. These cells live for long time and remain circulating in the blood, they are capable of responding very quickly if the same type of antigen enters the body again.

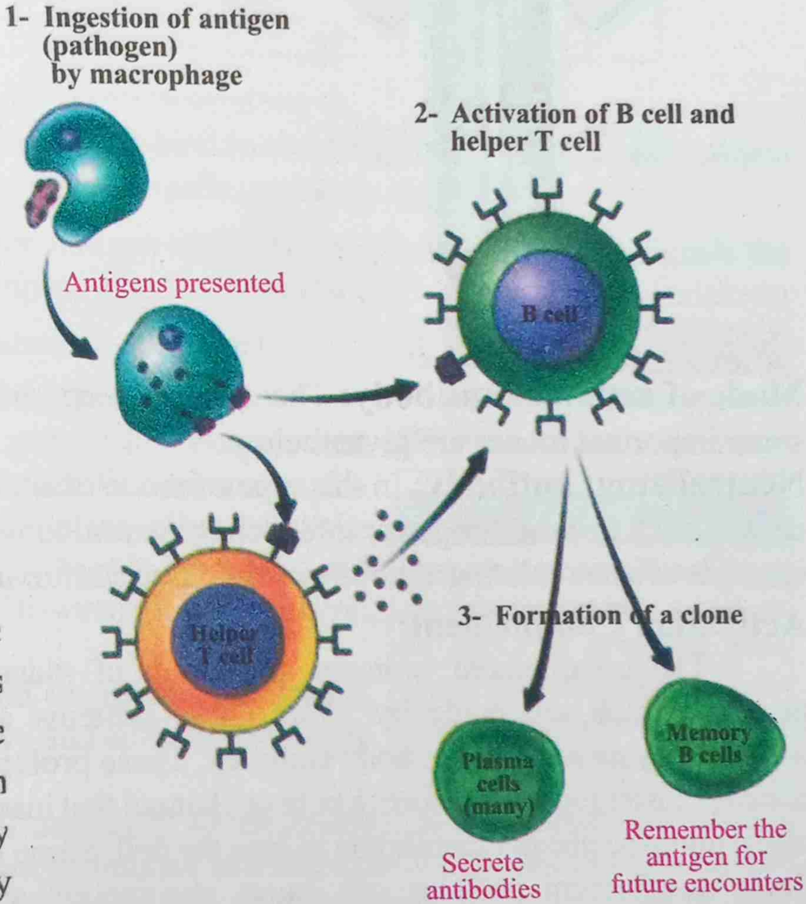


Fig. 13.11 Antibody mediated response

Structure of Antibody:

Antibodies are all globular glycoproteins and form the group of plasma proteins called **immunoglobulins.**

The basic molecule common to all antibodies consisting of four polypeptides chains two **long (heavy) chains** and two **short (light) chains. Disulphide bridge,** hold the chains together. Each molecule has two identical antigen binding sites which are formed by both heavy and light chains. The sequence of amino acids in these regions make the specific three dimensional shape which binds to just one type of antigen. This is the variable region which is different on each type of antibody molecule produced. The hinge region gives the flexibility for the antibody molecule to bind around the antigen.

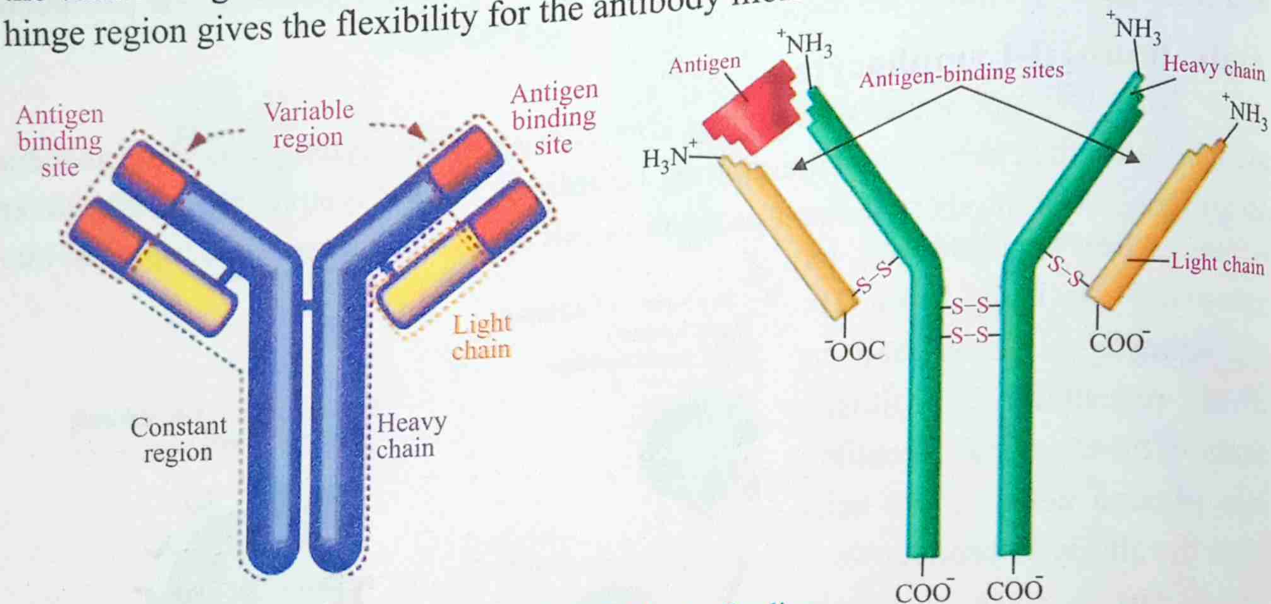


Fig. 13.12 Antibodies

Mode of action of antibody: There are different modes of action of antibodies, some important modes are given below.

Neutralizing antibody: In this type of mode of action of antibody, an antibody that defend a cell from an antigen or infection by neutralizing any effect it has biologically. An example of a neutralizing antibody in diphtheria antitoxin.

Activation Complement:

The complement proteins are group of plasma protein, which are made by liver. These proteins are activated by an antigen antibody complex. These proteins usually cluster together to form a pore or channel that insert into a microbe plasma membrane to lyse the cell. Some of these complement proteins can cause chemotaxis and inflammation. Due to these activities number of white blood cells increase at the site of infection.

Do you know?

There are 5 classes of antibodies i.e. immunoglobulin IgG, IgM, IgD, IgA and IgE.

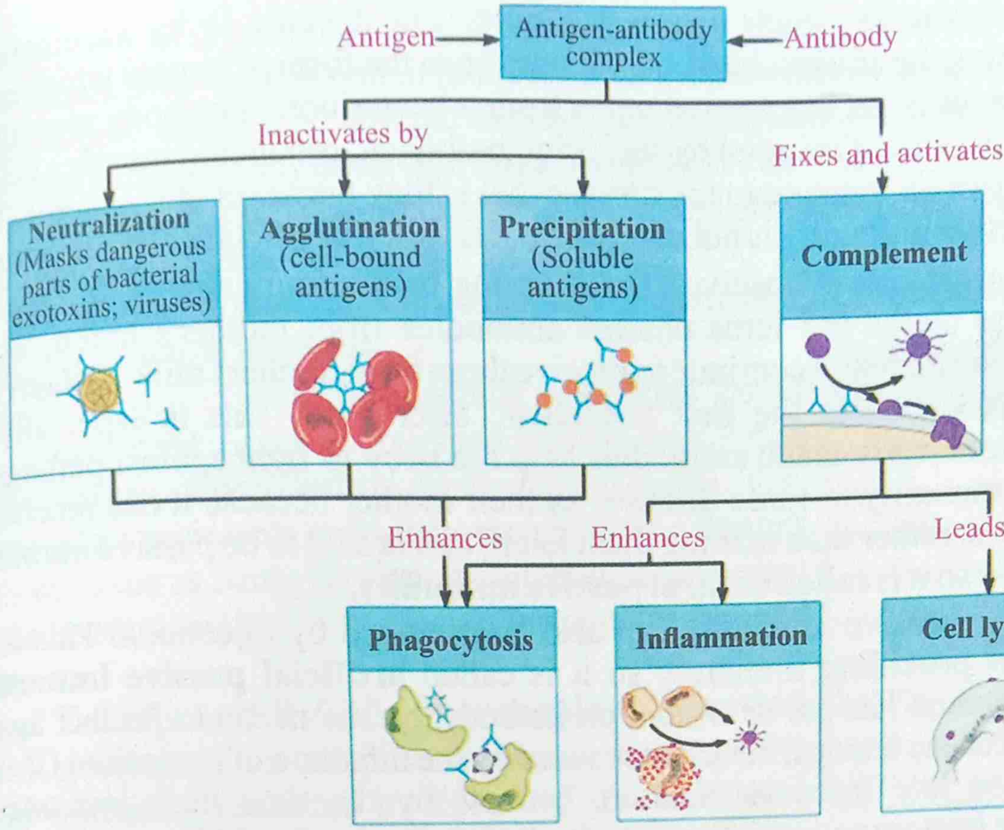


Fig. 13.13 Mode of action of antibody

Precipitating antigens: When antibodies bind to some free antigen, cause the antigen to precipitate out of solution, thus phagocytic cells can easily ingest them.

Facilitating phagocytosis: When antigen antibody complex is formed it signals the phagocytic cells to attack. This complex binds to the surface of macrophages, it facilitates phagocytosis.

Activity

Do you know what are auto grafts ?

13.3.4 Inborn and Acquired Immunity

As discussed in the early part of this chapter that inborn (innate) immunity is non specific and makes the first and second line of defence. On the other hand the acquired (adaptive) immunity is highly specific and develops in reaction of antigens. However, it takes several days to become fully functional.

Types of acquired or Induced immunity: Acquired immunity may be active or passive and either type may be acquired naturally or artificially.

Tit bits

Organ transplant is a medical procedure in which an organ is removed from donor body and placed in the body of recipient to replace a damaged or missing organ.

Active immunity: It is a kind of immunity which develops after contracting pathogen inside the body. The body has been stimulated to make a particular type of antibody and can produce these same ones more quickly in large quantity, if it is exposed to same pathogen again. The immunity has developed naturally, is called as **natural active immunity.**

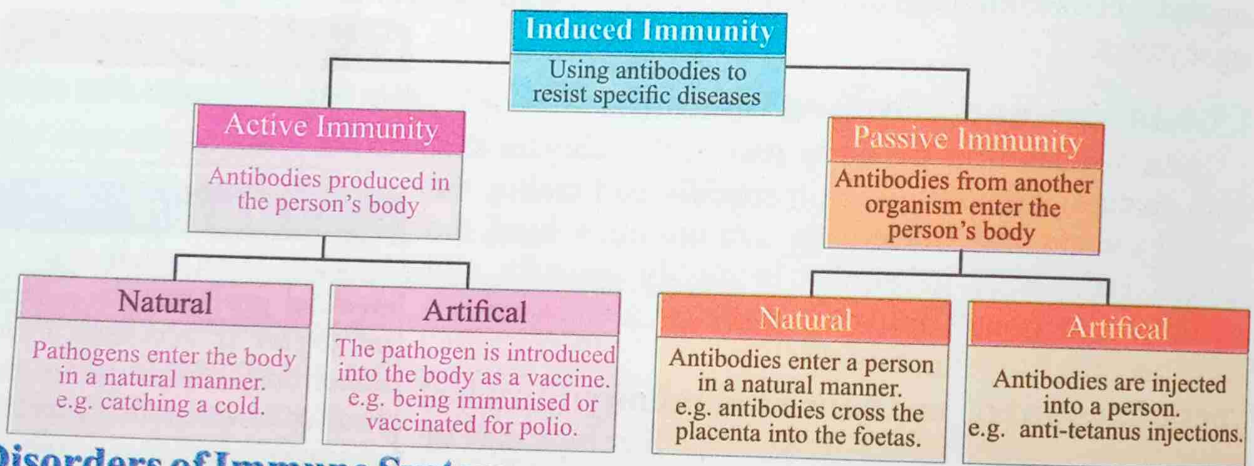
Another way in which active immunity can develop is by vaccination. This involves injecting the antigen into body. It may be in the form of viruses which have been made harmless, or as an inactivated toxin from a bacterium. The body responds in the same way as it would, if invaded by the living pathogen, producing memory cells which will make the person immune to the disease that is they may ever encounter it. This way of acquiring active immunity is not natural. So it is called **artificial active immunity.**

Passive immunity: It is observed that a young baby's immune system takes time to develop. In the uterus the fetus obtains antibodies from mother's blood, across the placenta. After birth, it will continue to receive them from mothers milk. **Colostrum,** thin yellow milk produced in the first few days after birth. This is especially rich in antibodies. These ready made antibodies help the baby to fight against pathogens. The baby has the immunity to same diseases as their mother because it has received ready made antibodies, rather than making them itself, this is said to be passive immunity as it occurs naturally so it is called **natural passive immunity.**

However passive immunity can also be provided by injections. This is not the natural way of providing immunity so it is called **artificial passive immunity.** For example if a person has cut or wound on its body, he/she needs to protect against the bacterium that cause tetanus. Tetanus is caused by the infection of bacterium *Clostridium tetani*. It is too late for a vaccination, because by the time their immune system responded, the bacterium would have multiplied and cause **fatal illness called tetanus.** Instead the person will be given an injection of antitoxin. The antitoxin will bind to the toxin produced by bacteria, rendering it harmless.

Passive immunity does not last as long as active immunity. No lymphocytes have been stimulated to produce clone of themselves, so no memory cells have been formed.

Flow Chart: 13.2



Disorders of Immune System

An autoimmune disorder is a condition arising from abnormal immune response to a normal body part. There are at least 80 types of autoimmune diseases. Nearly all body parts can be involved. Common symptoms include low grade fever, feeling tired, often symptoms appear and disappear. Some examples of autoimmune disorder are:

Allergies: Allergic diseases are number of disease conditions caused by

hypersensitivity of the immune system to some thing (Allergens) in the environment that usually causes little or no problem in most people. These diseases **cause hay fever,** food allergies, atopic dermatitis, allergic asthma etc. **Symptoms** may include red eyes, an itchy rash, sneezing, runny nose, shortness of breath or swelling.

The cause of allergies are usually genetic and environmental factors like pollen, metals, food, insect stings, drugs etc.

Usually antihistamine is given to allergic patients because in allergic conditions histamine production increases.

Transplant rejections: Transplant rejections occur when transplanted tissue is rejected by the recipient's immune system, which destroy the transplant tissue. This happens when recipients cells may recognize the donor's organ's or tissue as being foreign. As a result the recipient immune system activates against transplant organ and destroys it.

Role of T-Cells and B-Cells in transplant rejection

Rejection is an adaptive immune response via cellular immunity mediated by killer T-Cells. It induces apoptosis of T-Cells as well as humoral immunity mediated by activated B-Cells secreting antibody molecules. Although the action is joined with the components of innate immune response i.e., phagocytosis and soluble immune proteins. However different types of transplant tissues tend to favor different balances of rejection mechanisms.

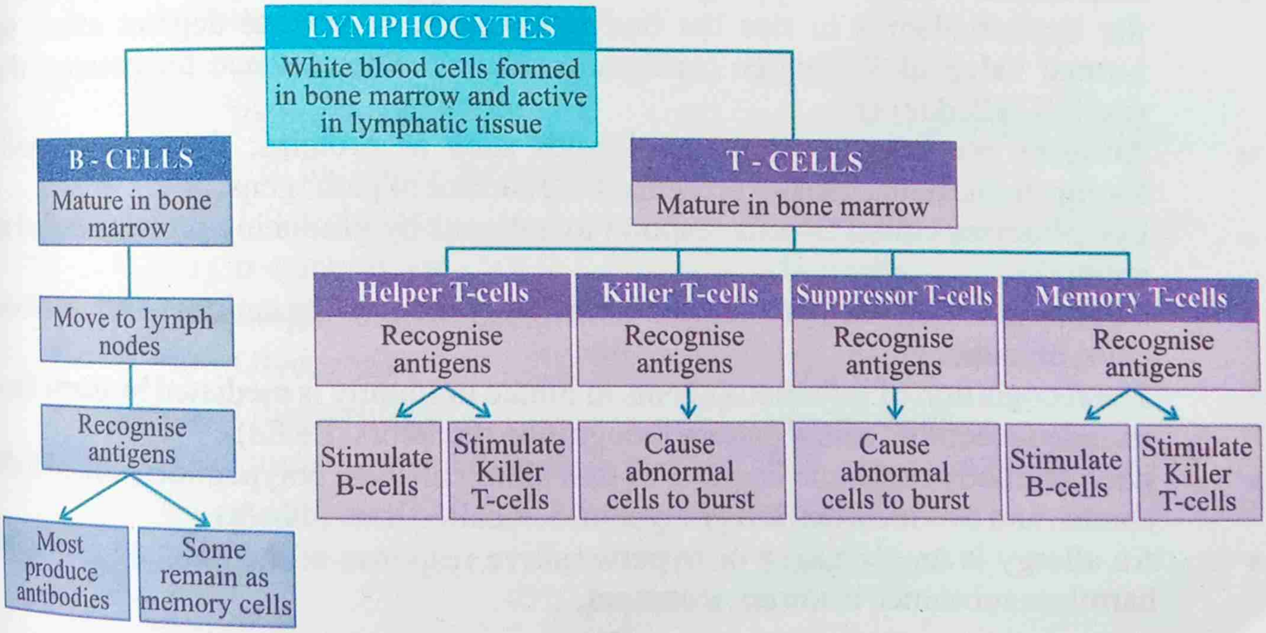
Do you know?

Stress can affect the way our immune system works. It can lead to increased level of cortisol which can blunt immune system. While positive emotions and a healthy life style may boost our immunity. Sleep deprivation can also impact.

Activity

Being too clean, can inhibit your immune system from functioning properly. Justify this statement by searching the information from different sources.

Flow chart 13.3 Different types of WBC



EXERCISE

Section I: Objective Question

Multiple choice Questions

A. Choose the correct answer.

1. Which of the following can not induce immunity?
   (a) Bacteria (b) Parasites
   (c) Virus (d) Worms
2. Skin is a ________ barrier.
   (a) Anatomical (b) Phagocytic
   (c) Physical (d) Inflammatory
3. Which among the following is anti-bacterial?
   (a) Interferon (b) hormone
   (c) Amylose (d) Protein
4. Which of the following is anti-viral?
   (a) Lysozyme (b) protein
   (c) Interferon (d) Hormone
5. Identify the phagocytic cells from the following combination.
   (a) Macrophage and Neutrophil (b) Macrophage and eosinophil
   (c) Lymphocyte and eosinophil (d) Eosinophil and neutrophil
6. Histamine is secreted by.
   (a) Epithelial cell (b) Red blood cells
   (c) Mast cells (d) White blood cells
7. Humoral immunity consists of:
   (a) Normal cells (b) Cytotoxic cells
   (c) Pathological cells (d) Immunoglobulin molecules
8. Which of the following secretes immunoglobulin.
   (a) T-lymphocyte (b) Macrophage
   (c) B-lymphocyte (d) Mast cells
9. Immunoglobulin are chemically.
   (a) Glycogens (b) Glycolipids
   (c) Glycoproteins (d) Lipoproteins
10. Colostrum is especially rich in.
    (a) Antibodies (b) Antigen
    (c) Sucrose (d) Histamine